

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-290 996

**The Sixth USA/USSR Symposium on Advanced Equipment and
Facilities for Wastewater Treatment, Held at
Cincinnati, Ohio on May 9-10, 1978**

(U.S.) Environmental Protection Agency, Washington, DC

Prepared for

**United States-Union of Soviet Socialist Republics Working Group on the
Prevention of Water Pollution from Municipal and Industrial Sources**

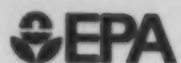
May 78

United States
Environmental Protection
Agency

Office of
Water Program Operations
Washington DC 20460

November 1978

PB 290996



Symposium on Advanced Equipment and Facilities for Wastewater Treatment



USA • USSR

U.S.A. — U.S.S.R.
Working Group
on the Prevention of
Water Pollution
from Municipal and
Industrial Sources

May 9-10, 1978

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read instructions on the reverse before completing)

1. REPORT NO.		2.	3. REQUESTING ORGANIZATION PB290996
4. TITLE AND SUBTITLE USA/USSR Symposium on Advanced Equipment and Facilities for Wastewater Treatment 6th in series		5. REPORT DATE May 1978	
7. AUTHOR(S)		6. PERFORMING ORGANIZATION CODE	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Water Program Operations Municipal Construction Division (WH-547) Washington, D.C. 20460		8. PERFORMING ORGANIZATION REPORT NO.	
12. SPONSORING AGENCY NAME AND ADDRESS USEPA Office of Water Program Operations 401 "M" Street, S.W. Washington, D.C. 20460		10. PROGRAM ELEMENT NO. 2B6647	
		11. CONTRACT/GRANT NO.	
		13. TYPE OF REPORT AND PERIOD COVERED	
15. SUPPLEMENTARY NOTES		14. SPONSORING AGENCY CODE EPA/700/02	
16. ABSTRACT The sixth cooperative USA/USSR symposium on Advanced Equipment and Facilities for Wastewater Treatment was held in Cincinnati, Ohio at the U.S. Environmental Protection Agency on May 9th and 10th, 1978. This symposium was conducted in accord with the sixth session of the Joint USA/USSR Commission held in the USA in November 1977. The eleven papers that were presented at the symposium, (six US and five USSR) are reprinted in English in this volume, in accord with the protocol signed by the delegation leaders on May 16, 1978. <i>Described advanced techniques and equipment for the treatment of municipal and industrial waste water.</i>			
17. KEY WORDS AND DOCUMENT ANALYSIS			
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Water Pollution Control	Advanced Equipment and Facilities for Wastewater Treatment		
18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 81	
	20. SECURITY CLASS (This page) Unclassified	22. PRICE A45-A41	

**Symposium on
Advanced Equipment
and Facilities for
Wastewater Treatment**

**U.S.A. — U.S.S.R.
Working Group
on the Prevention of
Water Pollution
from Municipal and
Industrial Sources**

May 9-10, 1978

Index

Preface

Opening Remarks

John T. Rhett

Welcome

Harold P. Cahill, Jr.

Address

Francis T. Mayo

Papers Presented at the USA/USSR Symposium

Westrick, James J., (US EPA), Removal of Volatile
Halogenated Organic Compounds by Activated Carbon

Myasnikov, I.N., Gandurina, L.V., (USSR), "Enhancement of
Mechanical Wastewater Treatment in the Petroleum Refining
Industry".

Crame, Leonard W., Henderson, U.V. (Texaco Inc., USA),
"Activated Sludge Enhancement: A Viable Alternative to
Tertiary Carbon Adsorption".

Genkin, V.E., Belevtsev, A.N., (USSR), "Electrochemical
Treatment of Industrial Wastewaters".

Warner, Howard P., English, John N., Kugelman, Irwin J.,
(US EPA), "Wastewater Treatment for Reuse and its
Contribution to Water Supplies".

Vorobyova, N.Y., Myasnikov, I.N., Gandurina, L.V., Kedrov,
Yu. V., (USSR), "Methods of the Varnish Industry
Wastewater Treatment".

Sebastian, Frank P., Doodeman, E.A., Micketts, John P.,
(Envirotech, USA), "Training for Use of Advanced Facilities
and Equipment for Wastewater Treatment".

Skirdov, I.V., Koltsova, S.I., Morozova, K.M., (USSR),
"Methods of Improvement of the Secondary Settling Tanks
Operating Efficiency".

Opatken, Edward J., Venosa, Albert D., Meckes, Mark C.,
(US EPA), "Contactor Evaluation for Ozonation of
Wastewater".

Pisanko, N.V., (USSR), "Combined Treatment of Industrial
and Municipal Sewages".

Collins, John W., (US EPA), "Closed Process Water Loop in
NSSC Corrugating Medium Manufacture".

Protocol

Appendix 1

Participants

Appendix 2

Papers Presented

Appendix 3

Future Program

Appendix 4

Symposium Program

Preface

The sixth cooperative USA/USSR symposium on Advanced Equipment and Facilities for Wastewater Treatment was held in Cincinnati, Ohio at the U.S. Environmental Protection Agency on May 9th and 10th, 1978. This symposium was conducted in accord with the sixth session of the Joint USA/USSR Commission held in the USA in November, 1977.

This symposium was sponsored under the auspices of the Working Group on the Prevention of Water Pollution from Municipal and Industrial Sources. The co-chairman of the Working Group are H.P. Cahill, Jr. of the United States Environmental Protection Agency and S.V. Yakovlev of the Department of Vodego in the Soviet Union.

The United States delegation was led by Harold P. Cahill, Jr., Director, Municipal Construction Division, U.S. Environmental Protection Agency. The Soviet delegation was led by Roald Slavolyubov, Department Chief of Main Administration, USSR State Committee on Building Construction.

The eleven papers that were presented at the symposium (six US and five USSR) are reprinted in English in this volume in accord with the protocol signed by the delegation leaders on May 16, 1978.

Opening Remarks

John T. Rhett

It is a great pleasure to open this sixth Joint US/USSR Symposium on Advanced Equipment and Facilities for Wastewater Treatment and I am delighted to see the wide-ranging interest and attendance. I would like to thank our Soviet colleagues for their strong support of these conferences, both here and in Moscow and my EPA colleagues here in the Cincinnati Environmental Research Center and in Washington, D.C. for their participation. I would also like to recognize the contributions of private enterprise to these symposia, through representatives, who are directly involved in environmental concerns.

The high degree of cooperation and coordination that is required to accomplish this international exchange of information is impressive. Bilateral scientific cooperative efforts like this to extend the boundaries of what is possible in pollution control deserve the highest priority. I am happy to see that the caliber and experience of the people involved reflect a high degree of concern for environmental protection in our respective governments.

As the sixth in a series, this is a logical extension of the continuing scientific and technical inquiry of members of this working group in methods of improving the generic types of wastewater and sludge treatment systems and those systems which allow recycling and reuse of wastewater, as an extension of the conservation ethic.

During the months since our exchange of techniques and ideas in Moscow last fall, we have enjoyed some significant developments in the program for which I am responsible—the federal government grant program to construct wastewater treatment systems in our municipalities. Our fundamental mandate, the Federal Water Pollution Control Act of 1972, was amended in December by a new clean water act. This act was passed by a substantial majority of members of the congress and signed into law by President Carter.

With the new law, we received authorization for the addition of significant funding to our program. Approximately \$24.5 billion should be available to extend the program for 5 more years, and allow us to plan ahead with more assurance that the necessary funds will be provided.

I realize five-year planning periods are not new in the Soviet Union, and I am not sure this type of planning system would be appropriate for our country. But, the type of continuing congressional and administration support we have been receiving is somewhat unique among our capital construction programs. Since we had completed committing more than \$18 billion in federal funds to projects by last fall, and many of our states had virtually exhausted their allotments, the arrival of this authorization in December was very fortunate. Communities can now proceed to make long-term commitments to treatment facilities construction without great concern for future provision of the federal share of 75 percent of the costs.

Some major provisions of the new Clean Water Act were designed to encourage the advancement of "alternative and innovative" technologies, which depart from and are significantly better than, the traditional treatment systems. I might add that the various incentives the Congress authorized would allow 10 percent more federal funds to go to projects

employing technologies which offer sufficient benefits and would reserve certain percentages of the funds allotted to the States exclusively for these types of projects. Further, these projects would enjoy certain advantages in cost-benefit comparisons with other projects to allow a higher initial capital investment.

In providing these additional incentives, the Congressional objective was to encourage municipalities to seriously examine the feasibility of adopting treatment processes that reclaim and recycle wastewater, and which consider land application and land treatment with particular respect to the small and rural communities. This is very much in concert with current objectives of EPA's policies to give careful consideration to the cost-effective alternatives. Further, our Agency Administrator, Douglas Costle, stated in his policy memorandum last fall, "the Agency is now fully in agreement with the intent of Congress to encourage the development of wastewater management policies that are consistent with the fundamental ecological principle that materials should be returned to the cycles from which they are generated."

The financial incentives I mentioned, coupled with the very real problems of limited water supplies and energy constraints which we have encountered, should be very influential in persuading many communities to view this alternative more positively than in the past. Groundwater and the prevention of contamination of underground supplies, of course, will be a principal concern in choice among the alternative solutions, and the planning details.

The major intent of these policy directions is to promote the type of technology that will:

- Cut costs;
- Simplify systems; and
- Enhance the recycling and recovery options and other resource saving benefits, such as energy, that can be obtained.

These initiatives and some others designed to recognize the special characteristics of small and rural communities allow the program a great deal more flexibility in providing for appropriate treatment. And this is a development of which I heartily approve.

Another significant addition to the program allows States to participate much more actively in program management through the provision of a portion of their allotments for securing the needed personnel resources. Not only the Construction Grants Program but other portions of the water pollution control effort, such as water quality planning and point source discharge permitting activities, can be supported through these allotments. As a corollary to this effort to add more program management resources, we have contracted with the U.S. Army Corps of Engineers to secure up to 600 engineers to aid us primarily in review of construction activities.

I have related a greatly abbreviated and over-simplified explanation of the intent of some of the major new water act provisions as they affect construction grants. We are currently in the process of issuing the pertinent regulations to implement these new mandates. We have reached the stage of publishing

a proposed version of the regulations which includes a considerable amount of public review and participation, secured to date. Our process allows for a formal comment period until the end of June, and we expect to issue our final version of the regulations in September.

Congress developed the new amendments during a long and intensive review of our program, and I would like to emphasize that we are very pleased with the outcome of that review and legislative effort. While it provided some important new directions to our water pollution control effort, our basic commitment and strategy for water quality remain the same, namely, the restoration and maintenance of the chemical, physical and biological integrity of our waters. The new amendments sustain the primary proposition that the best way to control the discharge of pollutants is through the application of uniform treatment technologies to classes and categories of discharges. At the same time, the amendments somewhat reoriented the direction of our criteria for "best available technology" away from any unnecessary control of additional increments of the so-called "conventional pollutants" toward a much more intense effort to identify and control toxic pollutants.

The subject of this symposium is central to the increased emphasis on toxics control. In the past 25 years, we have experienced a vast growth in our chemical industry. The U.S. Chemical Industry now has sales of \$113 billion a year. Its gross cost is twice that of our "Gross National Product." International trade in chemicals amounts to \$78 billion annually. Evidence of adverse effects to public health is accumulating at an increasingly rapid rate. And, incidents of contamination that pose clear hazards to health are even more alarming. Controlling toxic chemicals places a serious burden of responsibility on government officials. Our countries, as heavily industrialized nations, share a mutual concern to develop and apply the appropriate treatment technologies and management systems. I look forward to sharing the fruits of our mutual and continuing efforts in this field, and particularly to the results of this symposium. □

Welcome

Harold P. Cahill, Jr.

I always enjoy exchanging ideas with the people who are recognized and respected experts in their profession because it offers a challenge. And it is personally rewarding because of the chain of enduring friendships with my Soviet colleagues, which has grown out of these meetings and contacts.

At this Sixth Joint Symposium I am impressed, once again, with the relevancy of the topics for presentation. I am also impressed with their applicability to many of the problems in our Construction Grants Program, and the depth of scientific knowledge and experience that is represented.

I am looking forward to the papers to be delivered today, and I am hopeful from the program perspective that some methods to tame and subdue the "troika" of problems that are currently pulling at our program will emerge. I refer to three major problems of concern:

- First, toxic substances control;
- Second, runaway costs of conventional treatment, particularly for the highly sophisticated systems and particularly for the small and dispersed localities; and
- Third, strong pressures to develop new technological methods to enhance the conservation ethic in our pollution control systems and to develop the management approaches to provide the necessary degree of cooperation in our programs and flexibility in their application.

I am happy to note there are papers that would add to our base of knowledge about each one of these concerns, with the possible exception of management approaches. Our Deputy Assistant Administrator, John Rhett spoke of the new Clean Water Act amendments yesterday, and our EPA regulations being prepared. I will direct my remarks to some of the measures within EPA to meet this need to draw our programs into closer relationship.

Our Agency is currently developing a Regulatory Reform Program, and one of the problems it is designed to address is the impact of excessive costs and inflation. In general, and whenever possible we will be regulating only when we are confident that the benefits exceed the costs; and where we find more efficient ways of meeting environmental goals in the least costly manner.

Our Administrator Douglas Costle undertook, as his primary responsibility, the task of making EPA programs and operations more rational. Three things are being done to achieve this goal:

- We are improving our system for ranking environmental problems in priority order, and this includes the social and economic implications of achieving the goal.
- We are moving to improve the efficiency of our procedures, by cutting out both the excessive requirements and paperwork, and the uncertainty as to the requirements.
- And we are attempting to encourage the maximum amount of innovation in solving the pollution control problems.

New regulations are subjected to a very intensive review procedure by the public and others with particular expertise in the areas affected. A number of alternatives are presented to the Administrator, with analyses of their good and bad points, and an assessment of costs and benefits. The EPA system has

proven attractive to other Federal agencies and served as a model for part of an Executive Order on Regulatory Reform recently issued by the President. That Executive Order, I might add, calls for a careful analysis of all regulations that may have significant economic, social, geographic or governmental impact.

Our system for deciding what rules need to be written, and when, is also being reviewed. Often Congress provides the answers to these questions, or our Courts, but sometimes we do have the discretion to make a decision. Some of our more recent laws provide us more flexibility to address individual problems.

The Clean Water Act, Clean Air Act and Resource Conservation and Recovery Act, for example, provide special consideration to the innovative approaches in pollution control. It is in the form of a waiver allowing companies that can show progress toward developing innovative technologies to get an extension of time in which to meet the requirements. The basic criterion, of course, is that the new approach must be able to get the job done more cheaply, or more effectively, than what is already available.

We are also working internally and with other Federal agencies to be sure our regulations are consistent and complementary, and our enforcement efforts are coordinated.

As Mr. Rhett mentioned yesterday, we are moving to augment our program management resources through encouraging State assumption of program responsibilities and through employment of the Corps of Engineers to review construction activities.

The issue of project integrity and the quality of projects is of intense concern to us. We have more than 10,000 projects underway—projects valued at over \$21 billion are in the construction phase. We are moving to assure the soundness of projects under construction, and the incentives Congress provided should greatly improve the prospects for obtaining "quality" projects from planning. What do I mean by the term "quality project"? More than the engineering specifications, which are obviously essential, "quality" connotes the sensitive match between the technological aspects of a facility and the needs of the community it is designed to serve. This match should be in terms of size and cost, means by which the project is financed, its method of treatment, and the plans for operation and maintenance.

EPA has begun two activities to ensure that better quality projects are developed through facility planning. The first is to encourage our professional engineering community to give better consideration to innovative and alternative processes, and the second is to involve our private citizens who might be affected more actively in the planning process.

This Symposium should greatly aid in the expansion of the available technology. We still have a long distance to travel before we will have progressed as far as we need to go in the development of the necessary technologies. But our efforts are well grounded on solid scientific principles. There are a good many avenues to explore, and I am looking forward to the presentations today. □

Promoting the Use of New and Innovative Municipal Wastewater Treatment Technology in the United States*

Francis T. Mayo**

*Presented at the Joint US/USSR Symposium—May 9-10, 1978—U. S. Environmental Protection Agency, Cincinnati, Ohio.

**Director, Municipal Environmental Research Laboratory.

The Present Situation

For some time now the Environmental Protection Agency has been seeking effective means to implement the application of new and innovative technology in the field of municipal wastewater treatment in the United States. This has been difficult to achieve in the absence of a significant program to demonstrate the effectiveness and efficiency of new and innovative technology at full scale installations.

New and innovative technologies are considered to be those of recent development, not in common use throughout the country but with sufficient demonstrated capability for improved treatment success and efficiency to warrant broader application.

To a limited extent new technologies are being developed and marketed by private interests particularly if a proprietary position can be maintained in marketing the technology. Examples of this are: biological phosphorus removal (phostrip), deep shaft aeration, ultraviolet light disinfection. Some large municipalities, such as the Metropolitan Sanitary District of Greater Chicago and the Los Angeles County Sanitary District have taken other initiatives.

For the most part the pace has been slow in applying new technology in the field of municipal wastewater treatment.

From 1966 to date the Federal Government has financed a program for full scale demonstration of promising municipal wastewater treatment technologies, several of which are in more common use today. Some examples are high purity oxygen aeration, phosphorus removal by chemical addition, suspended growth and attached growth systems for nitrification and/or denitrification. The level of financing has been very modest in comparison to the need for demonstrations for the past several years.

However, during the past decade a number of advances in municipal wastewater treatment technology have taken place. Many warrant more widespread application in order to fully understand the advantages (or disadvantages) associated with them and to provide further opportunities for improvement with respect to operational stability, operation and maintenance costs, conservation of energy and performance efficiency. Table 1 identifies new and innovative technologies in three broad classifications:

- Proven but not used extensively
- Tested but need field verification
- Good ideas that need testing

Research is currently underway for a number of these technologies.

A New Program

In an effort to foster the more widespread application of innovative municipal wastewater treatment technology the Congress of the United States recently amended the Federal Water Pollution Control Act to provide increased dollar incentives to municipalities receiving Federal grants for the construction of such facilities.

The Federal construction grant assistance program to support the installation of municipal wastewater collection and

treatment facilities has been established at 5 billion dollars a year for fiscal years 1979 through 1982. A minimum of 1/2 percent of each state's share of these funds is to be used to support the application of innovative technology by increasing the level of the Federal grant from 75% to 85% of the cost of planning, design and construction of projects incorporating innovative technology.

In addition the new legislation provides that Federal funds may be used to fully replace such facilities if the innovative technologies that are used prove to be ineffective or bring about unreasonably high costs of operation and maintenance.

It is anticipated that these two major inducements will assist in overcoming the principal obstacles that now impede putting the newer technologies to use.

The new Federal legislation establishes a companion program requiring an evaluation of each project employing innovative technology and enjoying the 85% level of grant assistance. This evaluation program will be a cornerstone in documenting the effectiveness of the newer technologies and promoting more widespread application.

The Environmental Protection Agency is in the early stages of developing criteria for implementing of this new program to promote the application of a significant variety of innovative technologies in the field of municipal wastewater treatment including technologies developed in other countries. Efforts are now underway to develop a clearinghouse of information to assist in selecting the technologies that will be pursued. Data from the evaluation program mentioned earlier will be entered in the clearinghouse for availability to all interested parties. We fully expect that a number of innovative treatment technologies will be applied in the next three to five years and that the fruits of that effort will be increasingly apparent in the next decade in the form of more effective, and more efficient technologies for a wide range of municipal wastewater treatment needs.

Continuing Research Efforts

In order to enlarge our capability to test promising emerging water pollution control process technologies we are presently constructing a new Test and Evaluation Facility here in Cincinnati at the site of the Mill Creek Sewage Treatment Plant a short ten minute trip from here. The treatment plant has a capacity of 450,000 cubic meters/day (120 mgd) and employs primary treatment technology followed by single stage nitrification. The new 2.6 million dollar Test and Evaluation Facility will consist of a two story steel building with 3100 square meters (33,500 sq. ft.) of floor space including 2300 square meters (25,000 sq. ft.) of two story experimental area and 800 square meters (8,500 sq. ft.) of laboratory, storage and office space. The principal laboratory analytical support will be provided here at the Environmental Research Center.

The new test facility will support the research and development programs of five EPA laboratories located in the Cincinnati area. These are the Municipal Environmental Research Laboratory, the Industrial Environmental Research Laboratory, the Health Effects Research Laboratory, the Environmental Monitoring and Support Laboratory and the Newtown Fish Toxicology Station.

The Mill Creek Treatment Plant, with its industrial waste tank farm and its combination of industrial and municipal wastes and wastewaters, provides an ideal location for centralized inter-laboratory research on water pollution control. The facility will enjoy an extraordinary degree of flexibility because of the following features:

- Centralized service system with independently controllable sources of wastewater and sludges from several points within the treatment plant
- Overhead cranes and movable pilot equipment with quick connect/disconnect piping
- Flexible computer system for process control research and for data acquisition and processing
- Use of Automated Laboratory Services to provide rapid turn around in analytical work

Research at the new facility will include:

- Evaluating new treatment approaches for municipal and industrial wastes, wastewaters and sludges.
- Identifying toxic chemicals in and evaluating systems for removal of toxic chemicals from municipal and industrial wastewaters.
- Evaluating pollution control methods for combined sewer discharges.
- Developing improved process control methods for waste and wastewater treatment processes.
- Assessing environmental impacts, such as fish toxicity, of effluents from various wastewater treatment processes.
- Producing municipal or industrial effluents and renovated water for health effects research, such as mutagenicity studies.
- Evaluating industrial energy conservation methods including uses of wastes as fuels.
- Field testing of pollutant monitoring or sampling devices.
- Evaluating the treatment of drainage from sanitary landfills.

It will be our pleasure to continue to freely share the knowledge gained from these new national programs.

Perhaps future Joint US/USSR Symposia will provide opportunities to report on the success of our efforts. □

Table I
Innovative Technologies

Category and title	Proven but not used extensively	Classification Tested but needs field verification	Good idea that needs testing
A. Secondary Treatment Alternatives			
1. Intermittent Sand Filtration to Upgrade Lagoons			
2. Open Tank Oxygen Aeration			
3. Automation of Secondary Treatment Plants			
4. Fluidized Bed-O ₂ Biological Treatment			
5. Carrousel (deep oxidation ditch with mechanical aeration)			
6. Deep Shaft Aeration			
7. Airco Fall Reactor (clip-on upgrading technique)			
8. Orbital (Raceway brush aeration & flow equalization)			
9. Activated Bio-Filter (sludge return in a trickling filter)			
10. Weighing Agent Upgrading			
11. Rotating Biological Contactors			
B. Disinfection Alternatives			
1. Ultraviolet Radiation			
2. Sulphur Dioxide Dechlorination			
3. Ozone			
Air			
O ₂			
Electron Acceleration			
4. Chlorine Dioxide			
C. Nutrient Removal			
1. Single-stage Nitrification-Denitrification in an Extended Aeration Plant			
2. Fixed Film Nitrification and Denitrification			
3. Biological Phosphorus Removal (Phostrip)			
4. Digester Supernatant Ammonia Recovery			
5. AARP—Ammonia Removal & Recovery			

Category and title	Proven but not used extensively	Classification Tested but needs field verification	Good idea that needs testing
D. Toxics Removal (organics & heavy metals)			
1. Powdered Carbon Upgrading to Activated Sludge Plants with Regeneration			
2. Powdered Carbon Upgrading to Activated Sludge Plants without Regeneration			
3. Sodium sulfide or Ferrite Upgrading for Heavy Metal Removal			
4. Independent Physical-Chemical Treatment with Nitrate Addition (no regeneration)			
E. Preliminary & Primary Treatment Alternatives			
1. Flow Equalization <i>Dry & or dry/wet weather storage</i>			
2. SWIRL Primary			
3. Stationary Screens (Bauer Eng.) Discostrainer			
F. Special Applications			
1. Chemical Flocculation & Flotation for Ocean Discharge			
2. Renovation & Reuse through Groundwater Recharge			
3. Direct Municipal/Industrial Reuse			
4. Aluminum Sulphur Impregnated Concrete Pipe Trenchless Sewers			
5. Integrated Municipal Utility Services <i>Solid refuse Sludge Wastewater renovation Power production</i>			
6. Solar Energy for Digester Heating; Remote Facility Pumping Stations			

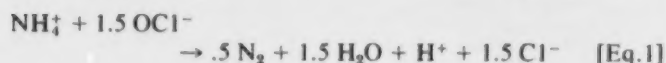
Category and title	Proven but not used extensively	Classification Tested but needs field verification	Good idea that needs testing
G. Small Flow Applications			
1. Centralized Management of Remote Treatment Facilities			
2. Septage Treatment			
3. Individual Home Water Conservation Treatment & Reuse Systems			
4. Alternating Soil Absorption Fields and Chemical Rejuvenation			
5. Recreational Vehicle Waste Disposal Systems			
H. Sludge Disposal Applications			
1. Sludge-Refuse Coincineration Co-pyrolysis			
2. Digester Supernatant Treatment with Anaerobic Trickling Filter			
3. Coal Sludge Incineration			
4. Sludge Pressure Dewatering & Autothermal Incineration			
5. Thermophilic Digestion <i>Aerobic Anaerobic</i>			
6. Multiple Hearth Pyrolysis			
7. Composting (Alternate Schemes)			
8. Compost Sterilization w/Heat			
9. Lime Stabilization			
10. Sludge Trenching			
11. Heat Treatment of Sludges Prior to Digestion to Improve Biodegradation			
12. Sludge Disinfection by High Energy Electron Irradiation			
I. Wet Weather Flow Treatment			
1. Vacuum Street Cleaning			
2. Sewer Flushing			
3. Porous Pavement			
4. Helical Flow Regulator			

Removal of Volatile Halogenated Organic Compounds by Activated Carbon

James J. Westrick

The removal of nitrogen from municipal wastewaters is required at various locations throughout the U.S.A. This can be accomplished by biological processes or by physical-chemical process. Biological processes are available which oxidize ammonia to nitrate (nitrification) ion and then reduce the nitrate nitrogen to elemental nitrogen (denitrification). Often the only nitrogen control requirement is based on nitrogenous oxygen demand, and can be satisfied by nitrification without the necessity of denitrification.

In cases when nitrogen removal is required, physical-chemical processes may be competitive. The process known as breakpoint chlorination is one which has generated considerable interest over the last five years. The process is based upon the chemical oxidation of ammonia to elemental nitrogen gas by aqueous chlorine. The probable overall reaction is summarized by Eq. 1.



Equation 1 illustrates the stoichiometric chlorine requirement is 1.5 moles of aqueous chlorine per mole of ammonia oxidized (7.6:1, weight basis). Other reactions, such as the formation of nitrogen trichloride and nitrate also consume chlorine and can result in a chlorine requirement on the order of 9:1 to 10:1 chlorine:ammonia-N (weight basis). Most municipal wastewaters in the U.S.A. contain ammonia nitrogen in the range 10-30 mg N/l, thus requiring up to 300 mg Cl₂/l for ammonia oxidation. There has been some concern that the application of high dosages of chlorine to wastewater could result in the formation of undesirable chlorinated organic compounds. This was a special concern after it was learned that chlorination of public drinking water supplies resulted in the formation of trihalomethanes, most notably chloroform. In the case of treatment of wastewater for discharge to a waterway or aquifer which serves as a drinking water source, production of chloro-organics could be a problem.

In order to examine the magnitude of the problem and the effectiveness of a possible remedy, a pilot plant study was undertaken at the EPA facility in Cincinnati. The objective was to operate a pilot plant system simulating as nearly as possible a treatment train producing high quality (reuse quality) effluent and using breakpoint chlorination for nitrogen control. The problem of the formation of chlorinated organics would be assessed together with the capability of activated carbon to remove the chlorinated organics and to prevent their formation. This paper addresses only the subject of the effectiveness of granular activated carbon for removal of halogenated organics.

The system used was a continuous flow pilot plant which would be subject to typical changes in wastewater characteristics. The process sequence was:

1. Secondary treatment by a trickling filter system
2. Tertiary lime clarification
3. Neutralization
4. Granular media filtration (GMF)
5. Breakpoint chlorination (BPC)
6. Granular activated carbon adsorption (GAC)

Because of the difficulty in measuring a large number of chloro-organics, the trihalomethanes, chloroform (CHCl_3), bromodichloromethane (BrCHCl_2), dibromochloromethane (Br_2CHCl) and bromoform (CHBr_3) together with carbon tetrachloride (CCl_4) and 1,2-dichloroethane ($\text{C}_2\text{H}_4\text{Cl}_2$) were the halogenated organics measured routinely. There was a growing body of data on these compounds in relation to water treatment practice, and it would be possible to compare results of wastewater chlorination with water treatment. The analytical procedure was not overly time consuming, therefore, the large number of samples would not impose an impossible burden on the analytical staff. Conventional pollution parameters were used to document the general efficiency of the system.

Description of Facilities

Raw wastewater was pumped continuously from a 1.8 m interceptor sewer serving residential and industrial areas of the City of Cincinnati. After treatment in a 0.6 l/sec trickling filter system, the wastewater was directed to the tertiary clarification-filtration system shown in Fig. 1. Secondary effluent, at a rate of 0.3 l/sec, was mixed with an average dose of 414 mg $\text{Ca}(\text{OH})_2/\text{l}$ to achieve a controlled pH of 11.2–11.5. After sedimentation, the effluent was neutralized with CO_2 and an automatically controlled amount of H_2SO_4 . Neutralized effluent was then passed through a granular media filter prior to treatment in the breakpoint chlorination-activated carbon systems.

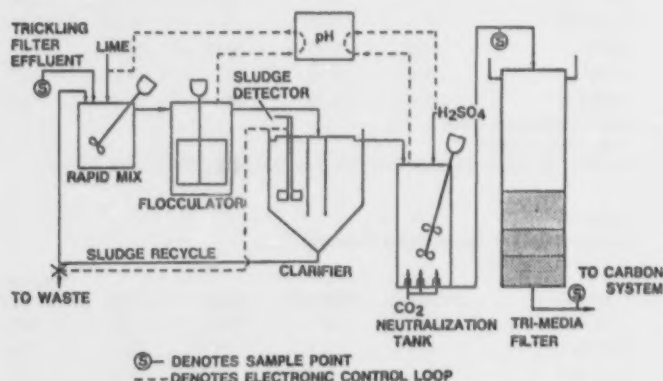


Figure 1.
Flow Diagram, Tertiary Lime Clarification-Filtration.

A schematic diagram of the chlorination carbon systems is shown in Fig. 2. Three activated carbon systems were operated in parallel. All were two-stage series expanded bed systems operating on filter effluent. In system 3, the filter effluent underwent BPC before application to the first stage carbon adsorber. In system 2, the BPC system was located between the first and second stage adsorbers. System 1 had no BPC and was used as a control.

Each activated carbon system contained 2.4 m (at repose) of Filtrasorb 400* granular activated carbon per stage for a total depth of 4.9 m. The hydraulic application rate to each adsorber was 15 m/hr for a resultant contact time of 10 min/stage (based

on empty bed volume, carbon at repose). The rate of flow to each carbon system was controlled by positive displacement feed pumps and monitored by rotometers. The diameter of each adsorber was 15 cm. The carbon was cleaned weekly by air scour and upward flow water wash, applied separately. The air rate was 150 m/hr and the water backwash rate was 37 m/hr.

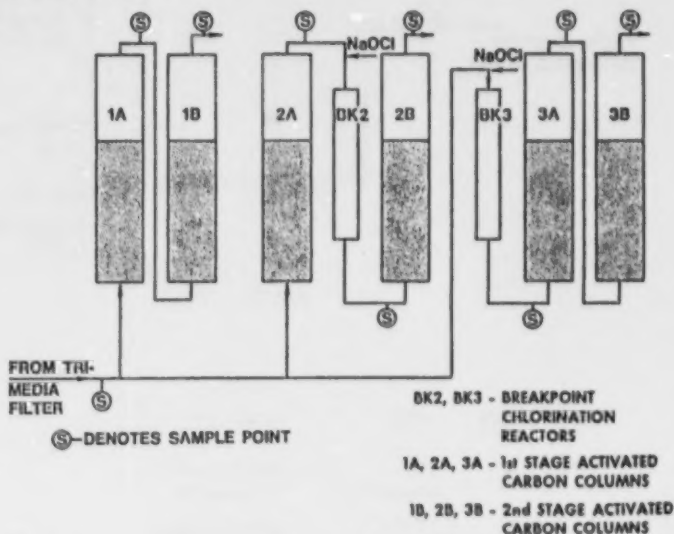
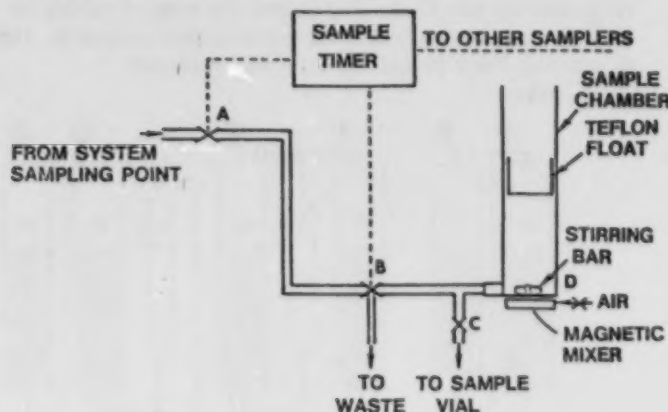


Figure 2.
Carbon-Chlorination System Schematic.

A special sampling apparatus was fabricated for use in obtaining composite samples for subsequent analysis of volatile organic compounds. A schematic of the apparatus is shown in Fig. 3. Effluents from the filter, breakpoint reactors and first and second stage carbon columns were sampled with this system. An in-house designed and fabricated electronic timer opened the solenoid valve A to allow the sample to flush the sample line for a selected time interval through a three-way solenoid valve B to waste. The timer then energized the three-way valve for an instant so that the sample was diverted into the sample chamber. The sampling interval, the flush time and the sample impulse time were all adjustable to allow for the proper sample volume and to insure complete flushing of the sample line. The electronic timer operated a total of nine samplers. The composite sample chambers consisted of 2-liter graduated cylinders equipped with flat bottoms and glass tube inlet-outlet ports. Teflon floats were machined to fit each sample chamber so that as the sample volume increased, the floats would ride up on the sample surfaces. These float-equipped chambers permitted the collection of composite samples in closed containers, and minimized the loss of volatile organics during the composite period. A few grains of sodium thiosulfate were added to each chamber at the beginning of each sampling period to prevent further reaction of chlorine and precursors during the compositing period. Each sample chamber contained a magnetic stirring bar which was used to mix the sample at the end of the compositing period. An air-driven magnetic mixer was located under the sample chamber

*A product of Calgon Corporation, Pittsburgh, Pennsylvania.

to drive the stirring bar. The system was operated 24 hours/day, 7 days/week for a period of 9 weeks. Composite samples were collected three times per week for analysis.



VALVE	TYPE	FUNCTION
A	2-WAY SOLENOID	DIRECT SAMPLE TO VALVE B
B	3-WAY SOLENOID	DIRECT SAMPLE TO CHAMBER
C	MANUAL TOGGLE	TRANSFER COMPOSITION SAMPLE TO VIAL & DRAIN REMAINDER
D	MANUAL NEEDLE	CONTROL MIXER SPEED

Figure 3. Automatic Composite Sampler for Volatile Halogenated Organics.

At the end of the composite period, the contents of each of the closed composite samplers were mixed with the stirring bars for a short period of time to assure that a representative sample would be withdrawn. Then valve "C" (see Fig. 3) was opened manually to allow the contents of the chamber to flow into the bottom of a 20 ml serum vial. The vial contents were displaced several times to minimize air contact and a convex meniscus was left at the top. The vials were then sealed with a teflon disc held in place by a crimped aluminum cap. After the samples were transferred to the sealed vials, the remaining contents of the sample chambers were drained, and the floats were lifted out. The sample chambers were rinsed with distilled water, if necessary, and a few grains of sodium thiosulfate were placed in each chamber for dechlorination of the next composite sample. The floats were then reinserted, and the sampler was ready for another composite period.

The experimental procedure was simply to operate the system under steady conditions, monitor the production of volatile halogenated organics (VHO) during breakpoint and monitor the removal of VHO by the activated carbon systems.

The procedure of Bellar and Lichtenberg was used to measure the six volatile halogenated organic compounds^(1,2). The volatile substances were purged from the sample with

helium and collected on an adsorbent trap (Tenax). The trapped organics were then introduced into a gas chromatographic column (1.8 m x 4 mm glass column packed with 60/80 mesh Tenax) by helium purging at elevated temperature. The gas chromatograph was equipped with an electrolytic conductivity detector operated in the halide mode. Ammonia interference was overcome by acidifying the samples before purging to avoid volatilization of ammonia. Peaks obtained as the output of the detector were identified by comparison with retention times of known standards. Concentrations were determined by comparison of peak heights with a standard curve.

Granular Activated Carbon Performance

Tables 1, 2 and 3 summarize the data on the six VHO compounds in the influents to the carbon columns. Chloroform was the only compound of the six VHO's that was detected consistently and in significant quantity in the samples taken around the activated carbon and BPC systems. Therefore, the major emphasis in the analysis of carbon performance is on chloroform removal.

Table 1
Concentration of Halogenated Organics
in influent to Columns 1A and 2A.

COMPOUND	AVERAGE	MEDIAN	MAX.	MIN.	% OF DAYS DETECTED
CHCl ₃	16*	10	2400	N.D.	84
BrCHCl ₂	1.1	N.D.	4.6	N.D.	44
Br ₂ CHCl	2.1	N.D.	9.7	N.D.	44
CHBr ₃	N.D.	N.D.	N.D.	N.D.	0
CCl ₄	3.1	N.D.	43	N.D.	48
C ₂ H ₄ Cl ₂	4.8	N.D.	44	N.D.	32

All concentrations—μg/l

N.D.—not detected

* Maximum value of 2400 μg/l (July 2 slug) omitted from calculation of average

Table 2
Concentration of Halogenated Organics
in influent to Column 3A

COMPOUND	AVERAGE	MEDIAN	MAX.	MIN.	% OF DAYS DETECTED
CHCl ₃	80*	60	900	20	100
BrCHCl ₂	6.9	5.3	23	N.D.	96
Br ₂ CHCl	4.3	3.9	17	N.D.	65
CHBr ₃	2.3	N.D.	22	N.D.	12
CCl ₄	4.9	2.3	58	N.D.	65
C ₂ H ₄ Cl ₂	4.4	N.D.	51	N.D.	69

All concentrations—μg/l

N.D.—not detected

* Maximum value of 900 μg/l (July 2 slug) omitted from calculation of average

Table 3
Concentration of Halogenated Organics
in influent to Column 2B

COMPOUND	AVERAGE	MEDIAN	MAX.	MIN.	% OF DAYS DETECTED
CHCl ₃	33	29	86	2.5	100
BrCHCl ₂	4.0	2.8	26	N.D.	75
Br ₂ CHCl	0.9	N.D.	6.3	N.D.	29
CHBr ₃	>.1	N.D.	0.8	N.D.	4
CCl ₄	1.7	2.0	5.8	N.D.	68
C ₂ H ₄ Cl ₂	0.5	N.D.	5.1	N.D.	14

All concentrations—μg/l

N.D.—not detected

Table 4

Carbon Column Identification

CARBON COLUMN DESIGNATION	CONTACT TIME (MIN)	INFLUENT	REMARKS
1A	10	—	1
1B	10	GMF	2
1AB	20	1A	1
2A	10	GMF	1
2B	10	BK2	2
2AB	—	—	3
3A	10	K3	4
3B	10	3A	2
3AB	20	BK3	5

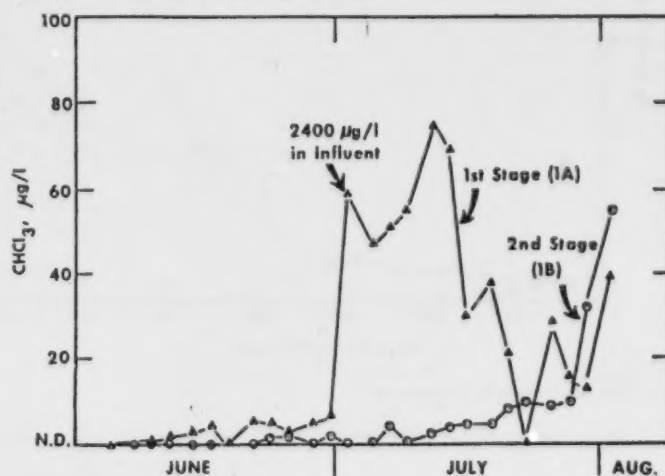
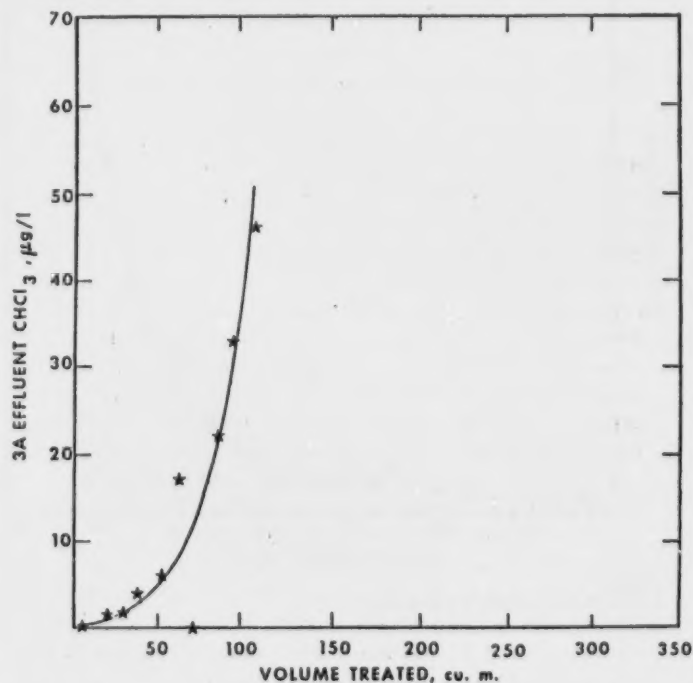
Remarks

1. Influent to 1A, 1AB and 2A included the 2400 $\mu\text{g/l}$ value of July 2. Capacity and breakthrough data are not useful.
2. 1B, 2B, and 3B all received wastewater treated with 10 min carbon contact. The CHCl_3 concentrations in their influents are variable but within a reasonable range. Capacity and breakthrough data from these second-stage columns are useful.
3. 2AB cannot be treated as a single 20-min contact time adsorber because of the chlorination reactor which altered the wastewater composition between stages.
4. 3A was exhausted before the July 2, 900 $\mu\text{g/l}$ influent concentration was observed. The capacity and breakthrough data to the point of exhaustion can be used.
5. 3AB was not exhausted at the time the July 2, 900 $\mu\text{g/l}$ influent concentration was observed. Capacity and breakthrough data are only marginally useful.

Referring to Fig. 2, each GAC system is treated as three adsorption systems. For example, GAC system 1 has a 10-min contact time adsorber treating GMF effluent (1A), a 20-min contact time adsorber treating GMF effluent (1A + 1B, designated here 1AB) and a 10 min contact time adsorber treating the effluent from adsorber 1A (1B). The carbon column designations are shown in Table 4. Adsorber 2 AB cannot be considered as a single 20-min system from a VHO removal standpoint because of the breakpoint between stages. As Table 4 indicates, the interpretation of the chloroform removal data for systems 1A, 1AB, 2A and 3AB is hindered because of the extremely large influent chloroform measurement in the samples of July 2. The effect of the large influx of CHCl_3 on July 2 on GAC system 1 is shown in Fig. 4, in which the CHCl_3 concentrations after 10 min and 20 min GAC contact are shown in a time plot. After 10 min contact, the CHCl_3 concentration on July 2 was reduced from 2400 $\mu\text{g/l}$ to 59 $\mu\text{g/l}$, while none was detected after 20 min contact time. After July 2, the first stage effluent was usually higher than the influent, while the second stage maintained low effluent levels for some time. In fact, the second stage exhibited a fairly uniform breakthrough curve, apparently unaffected by the July 2 event.

The CHCl_3 concentrations in the effluents from columns 3A, 3B, 2B and 1B are shown as a function of volume of wastewater treated in Figs. 5, 6, 7 and 8. These effluents were unaffected by the July 2 slug and illustrate the shape of the breakthrough curves and the relatively good fit of the smooth curves to the data points. After the breakthrough of CHCl_3 in the effluent of column 3A occurred (Fig. 5), the column was kept in service. Its capacity for removal of CHCl_3 was essentially exhausted, showing removal only when the influent concentration rose to much higher levels than usual. The effluent from 3A was often higher in CHCl_3 than the influent after breakthrough occurred. This was also observed in the carbon treatment of chlorinated river water ⁽³⁾.

The four breakthrough curves are shown together in Fig. 9 for comparison. Several superficial observations can be made from examination of the breakthrough curves. Locating the breakpoint chlorination system in the mid-carbon position resulted in about 20% longer running time before carbon broke through to a concentration of 5 $\mu\text{g/l}$. Examination of the breakthrough curves of system 3 for influence of contact time results in a somewhat unexpected observation. Using CHCl_3 concentration of either 5 or 10 $\mu\text{g/l}$ as the exhaustion criterion, 20-min contact time allows over 3 times the run length to exhaustion as 10-min contact time.

Figure 4.
 CHCl_3 in Effluents of GAC System 1.Figure 5.
 CHCl_3 Breakthrough, Column 3A.

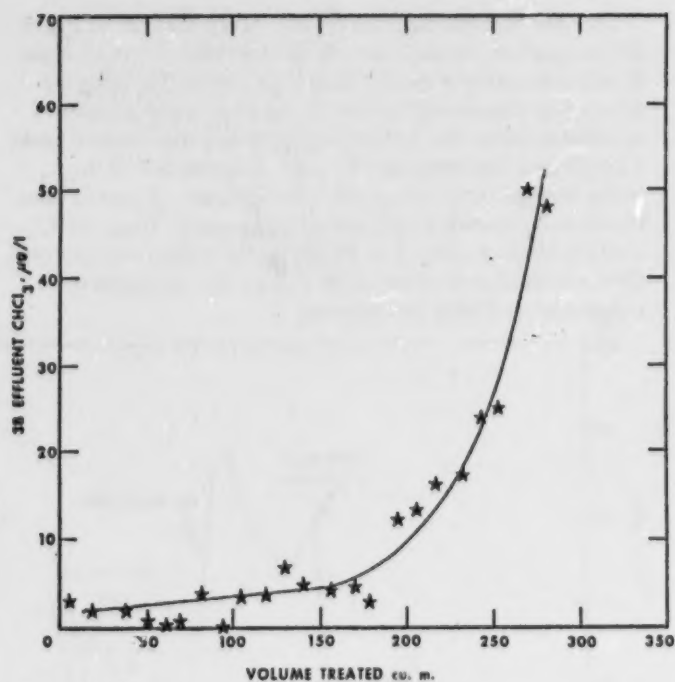


Figure 6.
CHCl₃ Breakthrough, Column 3B.

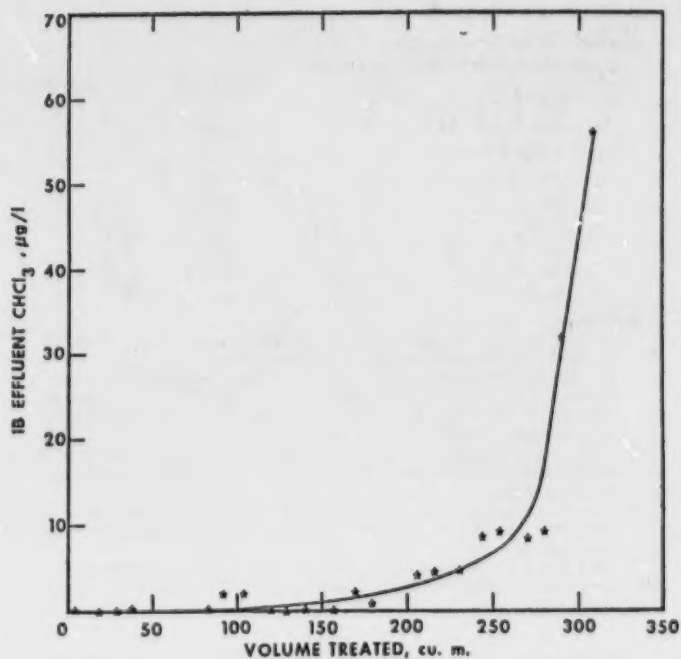


Figure 8.
CHCl₃ Breakthrough, Column 1B.

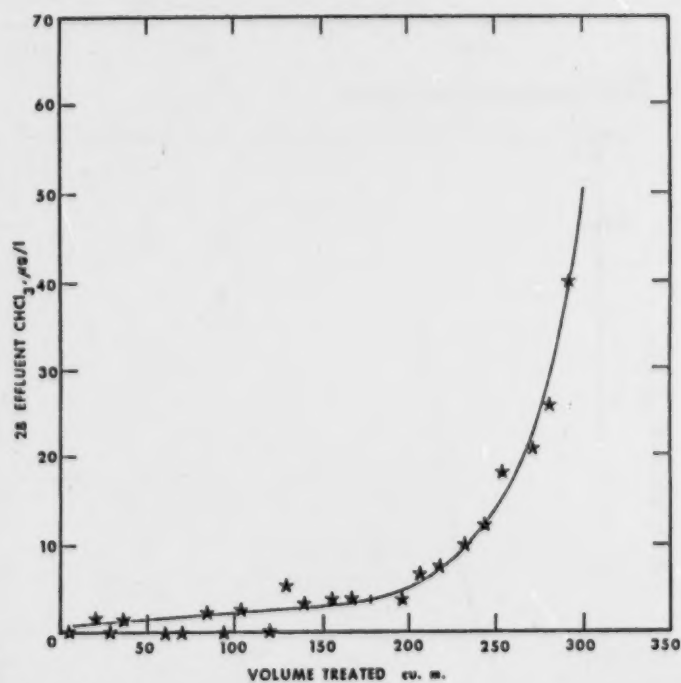


Figure 7.
CHCl₃ Breakthrough, Column 2B.

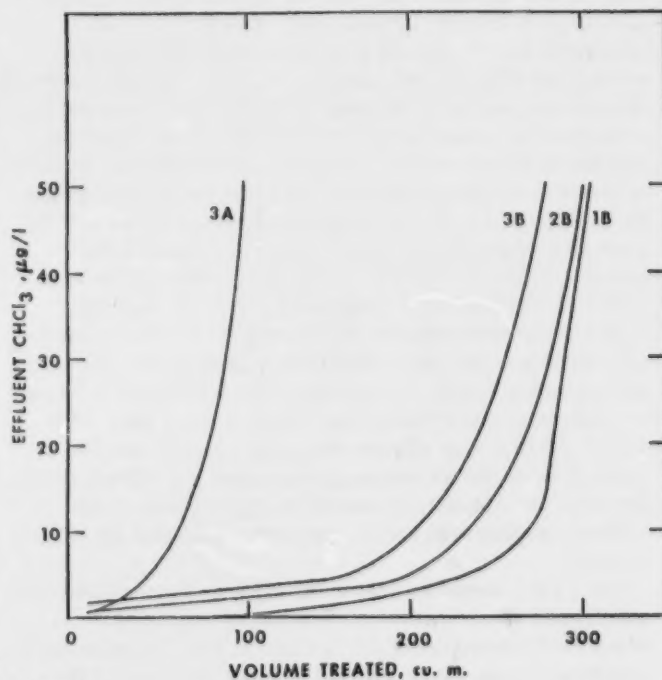


Figure 9.
Breakthrough Curves, CHCl₃.

Love, et al, found that doubling the contact time approximately doubled the bed life ⁽³⁾. Other work on the breakthrough of sewage organics showed a 20-min contactor had less than twice the service life of a 10-min contactor with TOC as the effluent criterion ⁽⁴⁾. Approximately 50 cu m and 165 cu m had been treated in system 3 when the effluents from

the first and second stages, respectively, reached a CHCl_3 level of $5 \mu\text{g}/\ell$. Since the volume of the 10-min contactor was 0.041 cu m and the volume of the 20-min contactor was 0.082 cu m the throughputs to an exhaustion criterion of $5 \mu\text{g CHCl}_3/\ell$ in the 10-min and 20-min contactors were 1200 and 2900 bed volumes, respectively. Carbon utilization rate can be defined as the weight of carbon exhausted per unit volume of wastewater treated. Using a bed bulk density of $420 \text{ kg}/\text{cu m}$, a 20-min contactor would be exhausted at a rate of $200 \text{ g carbon}/\text{cu m}$ wastewater treated, while the utilization rate of a 10-min contactor would be $340 \text{ g}/\text{cu m}$. This is a significant difference in performance which suggests that a weakly sorbed substance such as chloroform, longer contact times may give improved utilization of the carbon. A probable explanation is that because more strongly adsorbed organics are removed in the first stage, the competition for available adsorption sites is reduced in the second stage. As will be seen later, removal of competing organics in the first stage apparently allowed more efficient chloroform adsorption in the second stage. This could be especially important in considering treatment of polluted surface waters with activated carbon for removal of trihalomethanes. One approach often considered for installation of GAC in drinking water treatment works is replacement of filter sand with GAC. This approach usually results in contact times of only 4–8 min. A careful examination of the effects of contact time and removal of competing organics could result in lower GAC regeneration requirements for trihalomethane removal.

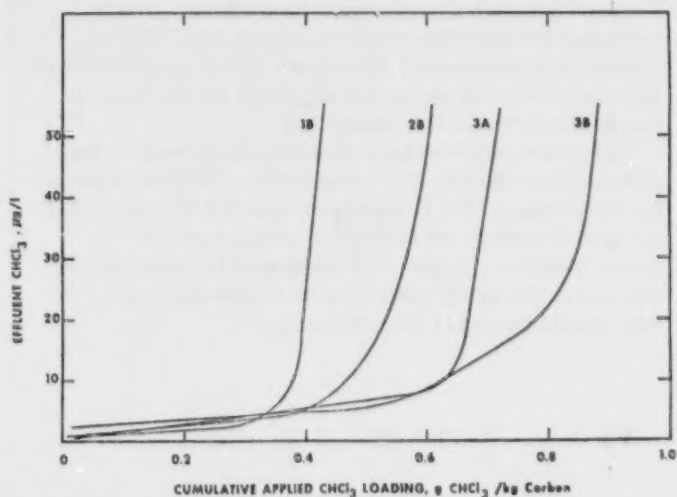


Figure 10.
 CHCl_3 Breakthrough As a Function of Applied CHCl_3 .

Fig. 10 shows the pattern of chloroform breakthrough as a function of cumulative weight of CHCl_3 applied to each 10-min contactor. The cumulative applied loading was calculated from the concentrations in the influent to each carbon column as designated in Table 4, with columns 3A and 3B treated as separate adsorbers. The "B" columns all were second-stage columns treating wastewater that had already been treated with 10-min carbon contact. Column 3A operated on chlorinated filter effluent. While the loading to each column was low, ($<$

$0.3 \text{ g CHCl}_3/\text{kg carbon}$) all columns produced very low effluent CHCl_3 . The differences in performance are only apparent as the cumulative loading increases and breakthrough occurs.

Table 5 shows the capacity of the carbon for chloroform removal in each of the 10-min columns. Carbon capacity is defined as the cumulative weight of the CHCl_3 removed per unit weight of carbon up to some point in the service time of the carbon. Values shown are for effluent breakthrough concentrations of $5 \mu\text{g}/\ell$ and $10 \mu\text{g}/\ell$ and also for the maximum capacity observed before complete exhaustion. As is evident from Fig. 10, nearly all the applied chloroform was removed up to the time of breakthrough. Therefore, the values in Table 5 reflect the same pattern as Fig. 10. Very little difference in carbon capacity can be detected at a $5 \mu\text{g}/\ell$ effluent level. At the $10 \mu\text{g}/\ell$ effluent level, 1B had removed less CHCl_3 than 2B, while 3A and 3B had both removed substantially greater amounts of CHCl_3 than 2B. At the point of zero removal or complete exhaustion, column 3B had exhibited greater capacity for chloroform removal than 3A.

Table 5
Capacity of Carbon for CHCl_3 Removal
10 minute contact time

	$\mu\text{g CHCl}_3$ removed/kg carbon			
	3A	3B	2B	1B
At $5 \mu\text{g CHCl}_3$ breakthrough	0.36	0.38	0.37	0.32
At $10 \mu\text{g CHCl}_3$ breakthrough	0.61	0.62	0.43	0.35
Maximum capacity	0.64	0.74	0.47	0.35

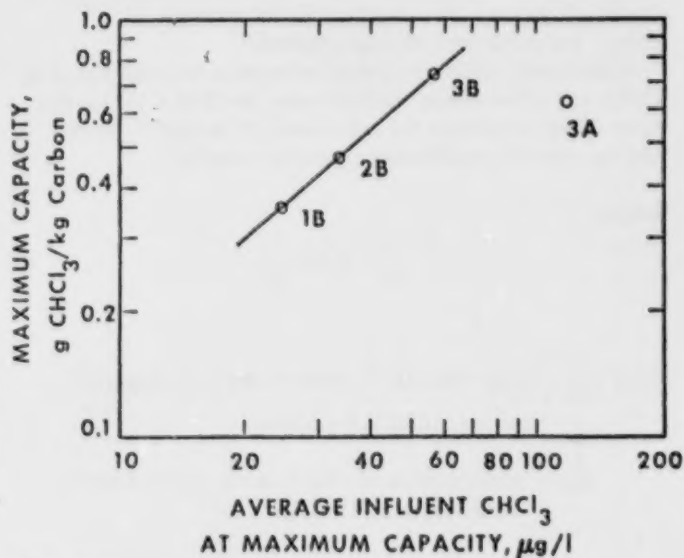


Figure 11.
Capacity of 10-Minute Contactors for CHCl_3 Removal.

The maximum capacity values are further illustrated in Fig. 11 where they are plotted against the flow weighted average concentration of CHCl_3 in the influents to each 10-min contactor up to the time of zero removal in an equilibrium type plot. The average influent concentration is analogous to the equilibrium concentration of solute and the maximum capacity can be considered the capacity at equilibrium. The three second-stage columns fit a Freundlich type equation very well:

$$\frac{X}{M} \max = 0.022 \quad \frac{0.87}{C_{inf}} \quad [5]$$

where $\frac{X}{M} \max$ = maximum capacity at complete exhaustion,
 $\frac{\text{g CHCl}_3 \text{ removed}}{\text{kg carbon}}$

C_{inf} = flow weighted average influent concentration, $\mu\text{g CHCl}_3/\ell$

The data point for column 3A lies below this line of best fit for the B columns indicating less efficient adsorption by 3A. The B columns all received wastewater which had been treated with 10 min contact with GAC, while 3A treated chlorinated GMF effluent. It appears from Fig. 11 that the CHCl_3 adsorption characteristics of the three B columns were similar even though the loading pattern was variable throughout the study and among the three columns. Another point of interest is that column 2B influent contained an average of 12 mg/ ℓ total chlorine residual of which 8.4 mg/ ℓ was free chlorine residual. Fig. 11 indicates no effect of chlorine on the CHCl_3 removal capacity of column 2B.

The less efficient removal of CHCl_3 by column 3A is almost certainly caused by competition of more strongly adsorbed sewage organics for adsorption sites. Removal of these sewage organics by the A columns reduces the competition for sites in the B columns and permits more efficient removal of chloroform in the second stage columns.

A laboratory batch equilibrium adsorption test was run using CHCl_3 in carbon-treated distilled water to which minerals had been added to simulate the salt content of sewage⁽⁵⁾. In this test the resulting equilibrium expression resulted:

where

$$\frac{X}{M} = 0.033 \quad \frac{0.84}{C_{eq}} \quad [6]$$

where $\frac{X}{M}$ = weight of CHCl_3 removed per unit weight of carbon, g $\text{CHCl}_3/\text{kg carbon}$

C_{eq} = concentration of CHCl_3 in the liquid phase at equilibrium, $\mu\text{g CHCl}_3/\ell$

This isotherm line, if plotted on Fig. 11, would lie above the B column data with nearly the same slope. This could imply that the organics discharged from the A columns did reduce the efficiency of the B columns for chloroform removal when compared with a CHCl_3 solution free of sewage organics.

While great significance should not be placed on the comparison of the B column data with the results of one batch test, it is encouraging that the capacity—concentration relationship obtained from the column data taken over a period of 9½ weeks under highly variable conditions appears reasonable in the light of the laboratory results. The system was not designed to obtain data for comparisons between batch and column tests. If that were the objective, numerous isotherms run on the wastewater actually being fed to the columns and columns spiked with known, constant concentrations of CHCl_3 would have been more useful.

The column data indicates that in a wastewater of a given quality, the capacity of carbon for removal of chloroform can be directly related to the influent concentration by a Freundlich-type expression. It is also apparent that the presence of competing organics can greatly reduce the efficiency of chloroform removal. For example, if column 3A had functioned as efficiently as the three B columns for CHCl_3 removal (if it had conformed to Eq [5] at its average influent concentration of 119 $\mu\text{g}/\ell$) its capacity would have been 1.41 g/kg, more than double its actual capacity. The data also indicate that applying an average of 12 mg/ ℓ total residual chlorine does not diminish the efficiency of carbon for removing chloroform.

Bromoform was never detected in the effluent of any of the carbon columns. BrCHCl_2 was nearly always found in the influent to carbon system 3. The first detectable BrCHCl_2 in the effluent from 3A occurred after 2000 bed volumes of chlorinated filter effluent when an average concentration of 12 $\mu\text{g}/\ell$ had been treated. At that time 0.06 g $\text{BrCHCl}_2/\text{kg carbon}$ had been removed. Considering column 3AB as a whole, consistent breakthrough was not observed until 3500 bed volumes had been treated. This shows the same effect of more efficient removal by the second stage than the first stage as was evident from the chloroform data.

Carbon tetrachloride began appearing consistently in the effluents from all three A columns when ~ 2500 bed volumes had been treated. The B columns contained CCl_4 only in 2–3 samples throughout the project and then in very low concentrations (< 2 $\mu\text{g}/\ell$). The amounts of the other specific organics in the carbon influents were too low and too infrequently present to merit discussion.

Conclusions

A pilot plant was operated continuously for nine weeks. Monitoring of six volatile halogenated organic compounds around the breakpoint chlorination-activated carbon systems resulted in the following conclusions:

The breakthrough of chloroform in the effluents of the carbon contactors was very sharp, with quite low effluent concentrations (generally $< 10 \mu\text{g}/\ell$) up to the point of breakthrough. After exhaustion the chloroform concentration in the carbon effluent was often higher than the influent concentration.

The service life of the 20-minute contactor treating chlorinated tertiary filter effluent was much more than twice that of a 10-minute contactor. The carbon utilization rate of the 20-minute contactor treated as a single-stage contactor was 200 g/cu m, compared to a utilization rate of 340 g/cu m for the 10-minute contactor, with $5 \mu\text{g CHCl}_3/\ell$ as the exhaustion criterion.

The capacity of the second stage columns to remove chloroform was a precise function of the average influent concentration. The first stage column removed CHCl_3 less efficiently than the second stage column, presumably because more strongly adsorbable organics were preferentially adsorbed in the first stage, thereby reducing the competition for adsorption sites in the second stage.

The removal of chloroform by carbon was not affected by the presence of 12 mg/l of the total residual chlorine. □

REFERENCES

- Bellar, T. A., and Lichtenberg, J. J., "The Determination of Volatile Organic Compounds at the $\mu\text{g}/\ell$ Level in Water by Gas Chromatography," U.S. Environmental Protection Agency Report No. EPA-670/4-74-009, November 1974.
- Symons, J. M. et al., "National Organics Reconnaissance Survey for Halogenated Organics," *Jour. American Water Works Assn.*, 67:634(1975).
- Love, O. T. Jr., et al., "Treatment for the Prevention or Removal of Trihalomethanes in Drinking Water," Appendix 3 to *Interim Treatment Guide for the Control of Chloroform and Other Trihalomethanes*, Water Supply Research Division, U.S. Environmental Protection Agency (June 1976).
- Westrick, J. J. Unpublished Data.
- Cohen, J. M., Middendorf, R. J., and Dobbs, R. A., "Adsorption of Volatile Halogenated Hydrocarbons: Correlation with Molecular Properties," Unpublished Report.

Enhancement of Mechanical Wastewater Treatment in the Petroleum Refining Industry

I.N. Myasnikov., L.V. Gandurina

Mechanical treatment methods such as sedimentation and pressure flotation play an important part in the treatment of petroleum refinery wastes. These processes being utilized as a primary treatment provide the removals of coarse dispersed matter, emulsified oil substances, colloidal solids, which affect significantly the operation of the biological system and the treatment system as a whole.

Therefore ways of improving the effectiveness of pressure flotation and sedimentation processes become of practical importance. One of them is the treatment of wastewaters with chemicals such as coagulants and flocculants. The application of the latter maximizes removals of fine dispersed stable colloids from wastewaters thus optimizing treatment efficiency of the process.

In the USSR inorganic coagulants -salts of aluminum and iron (1)- are most commonly employed for treating wastes. In recent years waste materials from various industrial processes containing aluminum, ferrous and ferric salts and mixtures of them (2-4) are used as coagulant aids.

Lime milk is added to maintain the required pH in wastes.

To optimize chemical treatment inorganic coagulants are increasingly replaced with high molecular weight organic flocculants or used in combination with the latter. Cationic flocculants are most effective in treating wastewaters. Several types of flocculants applied in treatment of petroleum refinery wastes are presented in Table I.

Table I
Characteristics of cationic flocculants

TRADE MARK OF FLOCCULANT	EXCHANGE VOLUME MG-EQUIV/G AS CL-ION	(η) IN 0.1 SOLUTION OF NaCl DL/G	η VISCOSITY/ CONCENTRATION, DL/G 1% AQUEOUS SOLUTION
BPK-101	4.56	—	1.96
BA-102	2.8	0.3	1.18
BA-112	3.2	0.4	2.08
BA-212	3.6	0.2	0.28
I2C ₁	1.5	0.3	1.18
BPC-411	4.67	0.5	0.17

Efficiency of sedimentation treatment of petroleum refinery wastewaters, treated with chemicals

Effect of inorganic coagulants on the level of petroleum refinery wastes treatment and their optimum dosages depend on pollutant concentration, their dispersion, the pH of wastes being treated (1-4). It has been found that doses of inorganic coagulants vary in the range of 50 to 150 mg/l. The residual concentration of oil substances is 10-15 mg/l with initial concentration of 50-175 mg/l. Simultaneously reduction in SS concentration and COD value takes place.

Nonionic and anionic flocculants used in conjunction with inorganic coagulants allow to improve the efficiency of clarification process, to reduce dosages of inorganic coagulant (Fig. 1), and to replace completely inorganic coagulants if cationic flocculants are employed (Fig. 2). From data given above it is apparent that treatment efficiency depends on the nature of a flocculant.

Among nonionic and anionic flocculants, polyacrylamides varying in molecular weights and degree of hydrolysis (PAA, PAA-R, PAA-G) provide the most effective clarification of

petroleum refinery wastes. Doses of above given flocculants range from 0.5 to 1 mg/l.

According to decrease in effectiveness, tested cationic flocculant may be schematically given in the following sequence: BA-212 > BA-112 > BPK-101 > 12C_n. Optimum dosages of flocculants having the same nature (BA-112, -212, 12C_n) is 10 mg/l, the optimum dose of BPK-101 flocculant is 5 mg/l. It seems to be due to higher value of total electrical charge (exchange volume) of BPK-101 flocculant (Table 1).

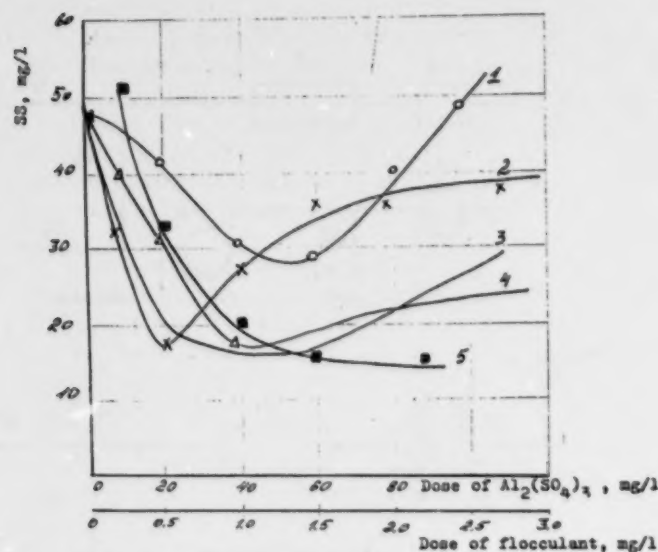


Figure 1. Treatment efficiency of petroleum refinery wastewater by sedimentation process as a function of flocculant (1-4) and coagulant (5) dosages. 1-4-Concentration of $Al_2(SO_4)_3$ is 24 mg/l; Concentration of SS (initial) mg/l: 1-4- 57mg/l; 5- 81mg/l; Flocculant: 1- PBC-M, 2-PAA-G, 3-PAA, 4- PAA-R.

The most important factor which determines effectiveness of purifying wastewaters, treated with any coagulant and flocculant, is the achievement of optimum hydrodynamic conditions for mixing and floc formation.

The first stage of mixing (rapid mixing) provides complete and rapid distribution of chemicals in a body of water as well as determines numerical concentration of initial particles in coagulated suspension and their distribution on size.

The second stage (slow mixing) promotes the formation of flocs of certain size and structure thus providing optimum condition for their separation.

Studies carried out have shown that optimum mixing is achieved at velocity gradient G_2 of 94-120 sec^{-1} and mixing period t^1 of 20-60 sec (Fig. 3). Optimum floc formation is obtained at velocity gradient G_2 of 20-25 sec^{-1} , which corresponds to Camp criterion $G_2 t_2 = 24000-30000$ and mixing period of 20 min.

Kinetic relationships between efficient clarification of oil wastes treated with BPK-101 and BPC-411 flocculants at optimum floc formation conditions and detention period are illustrated in Fig. 4. From data obtained it is apparent that

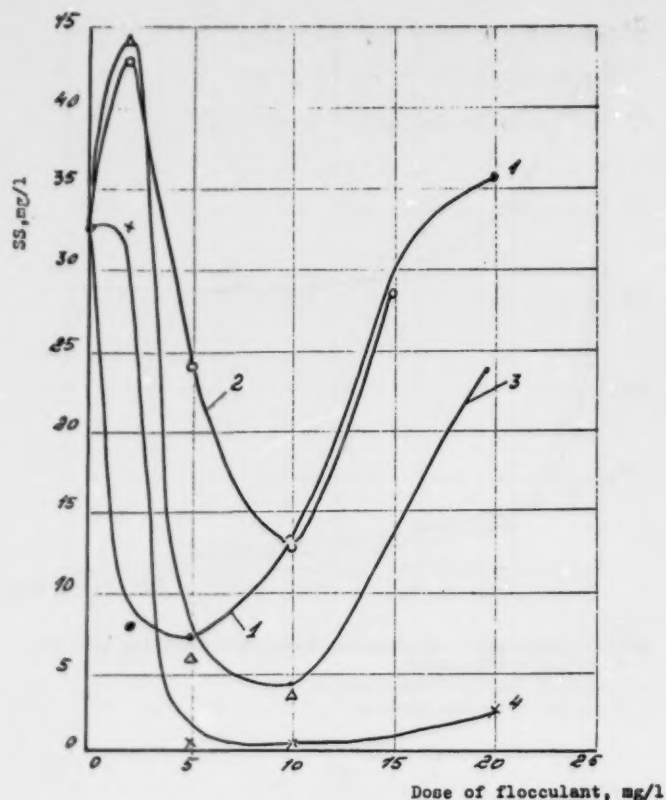


Figure 2. Concentration of suspended matter in treated petroleum refinery wastewater as a function of flocculant doses. Initial concentration of SS = 39.5 mg/l; 1- BPK-101; 2- 12C_n; 3- BA-112; 4- BA-212.

most of the contaminant is removed by 30 minutes settling. Residual concentration of suspended matter is from 4 to 11 mg/l. As the results obtained from kinetic studies indicate, treatment efficiency and settling velocity of flocs decrease under non-optimum mixing conditions (Fig. 4).

Therefore it is necessary to include mixing and floc formation chambers in treatment scheme of petroleum refinery wastewaters.

Flotation of coagulated and flocculated wastewaters.

In petroleum refinery waste treatment technology the following flotation systems with addition of chemicals are used:

- full flow system, when all the flow of wastewater to be treated enters a saturation tank;
- recycle system, when from 20% to 50% of clarified effluent is supplied to a saturator.

Chemicals are fed into the system at the suction end of the pump where wastes enter the saturation tank (Fig. 5a), or into recirculating pipeline ahead of pressure tanks (Fig. 5b) or the flotation cell (Fig. 5b).

The mixer and the floc formation chamber are included in the latter treatment scheme in order to achieve optimum conditions for mixing and floc formation.

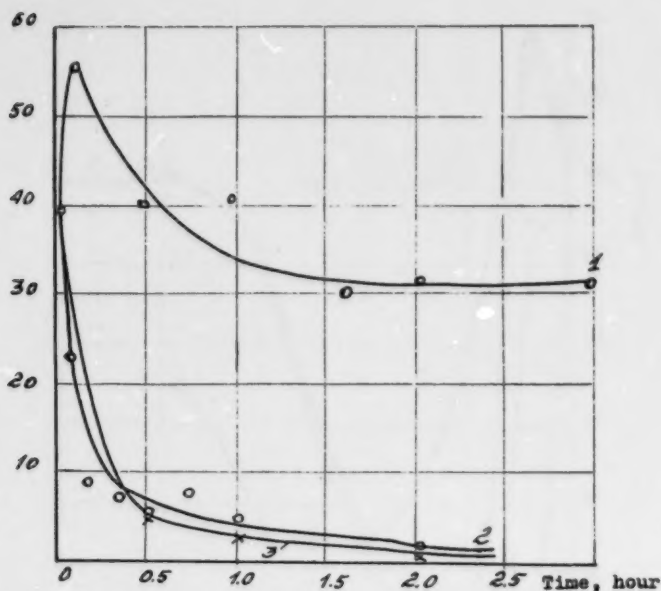


Figure 3.
Kinetic of sedimentation of petroleum refinery wastes treated by BPK-101 (1,2), BPC-411(3) flocculants.

1- nonoptimum conditions for floc formation;
2-3- optimum floc formation conditions.

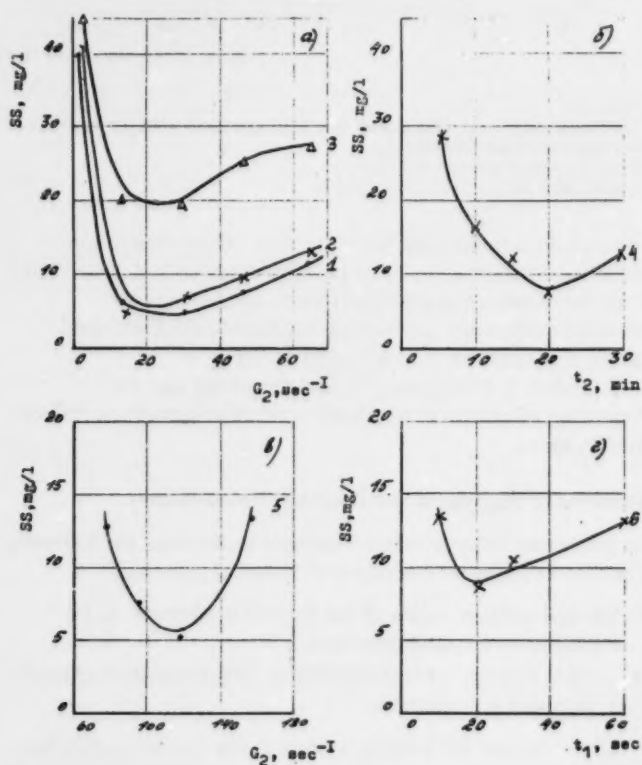


Figure 4.
Relationship between suspended solids removal from petroleum refinery wastes, treated by a flocculant and clarified during 0.5 hour, and mixing conditions.

G_1 , sec^{-1} : 1,4, 6- 94; 2,3- 117,5;
 G_2 , sec^{-1} : 4,5,6- 25;
 t_1 , sec: 1,4,5- 60; 2,3- 20;
 t_2 , min.: 1,2,5,6- 20; 3- 10.

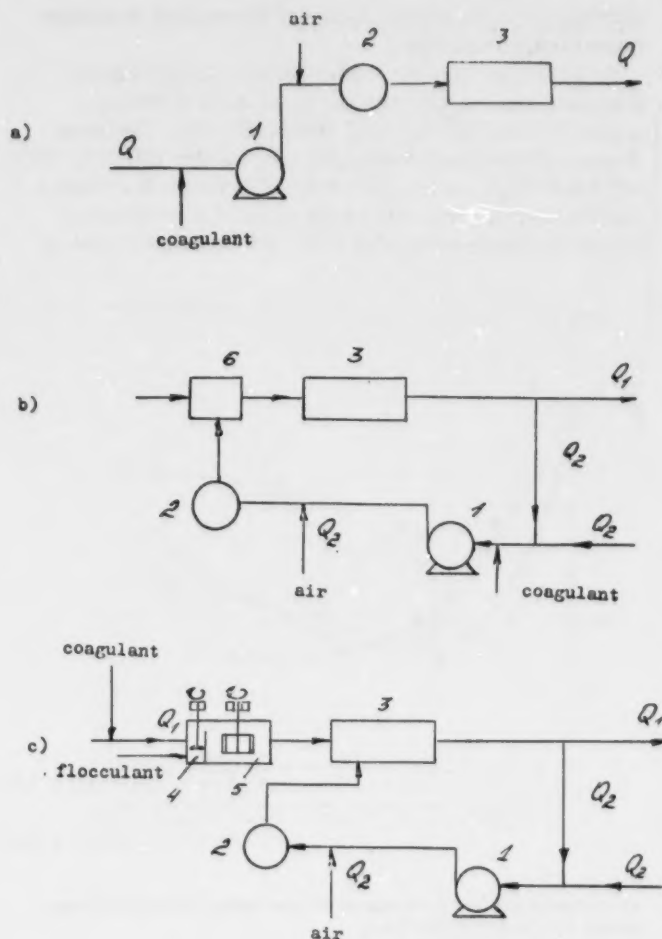


Figure 5.
Typical schemes of flotation units.

a) direct flow, b) recycle

1- pump for wastewater,

2- saturation tank, 3- flotation cell, 4- mixer,

5- floc formation chamber, 6- chamber for mixing wastewater and effluent from a saturation tank.

As the majority of existing full-scale flotation facilities operate according to schemes, making provision for chemical addition to wastes prior to entering the saturation tank or the pump, the study of effective applicability of chemicals in such schemes is of practical concern.

The results of treating wastewaters in a 600 cu.m/hour full scale flotation unit, a schematic of which is shown on Fig. 5b, are presented in Table 2. The unit consists of a typical radial flotation chamber with a diameter of 15 m.(3), a saturation tank of barbotage type (2) to saturate wastes with air, a chamber of "tube in tube" type for mixing wastewater with an effluent from a saturator (6), a pump (1). Air is supplied by an ejector (5). A pressure of 58,8 lb/sq. in. is maintained in a saturation tank. 50 percent of treated wastewater is saturated with dissolved air. Chemical (aluminium sulfate) is introduced into the suction end of the pump ahead of the saturator. Aluminium sulfate at dosages of 75 to 120 mg/l and BPK-101 flocculant have been tested. After passing through mechanical treatment

Table 2
Effectiveness of treating petroleum refinery
wastes in the full scale flotation unit

CHEMICAL	DOSE OF CHEMICAL MG/L	CHARACTERISTICS OF WASTEWATER						REMOVAL EFFICIENCY IN %		
		SS MG/L		COD MGO/L		OIL SUBSTANCES MG/L		SS	COD	OIL SUB- STANCES
		BEFORE TREAT- MENT	AFTER TREAT- MENT	BEFORE TREAT- MENT	AFTER TREAT- MENT	BEFORE TREAT- MENT	AFTER TREAT- MENT			
Al ₂ (SO ₄) ₃	75	96	33	327	225	41	16.3	66	31	60
	75	75	34	354	212	52	18	55	40.1	65
	75	85	25	362	216	50.8	11.3	71	40	78
	75	94	22	319	162	37.5	9.1	77	49	76
	100	—	—	221	106	63.4	11	—	52	82.5
	100	—	—	—	—	50	18	—	—	65
	100	—	—	245	107.5	67	29	—	—	57
	100	—	—	442	185	28	11	—	58	61
	120	48	9.5	197	150.5	30	2.0	80	24	93
	120	54	34	155	97	26	7.0	37	37	73
	120	23	—	—	—	37.5	11	—	—	71
	120	—	—	—	—	—	—	—	—	—
BPK-101	3.0	24	39	177	129	56.5	—	—	27	—
	6.4	59	17	181	155	86	19	71	70	78
	5.0	80	10	180	64.6	96	22	87.5	64	77
	5.6	64	13	198	—	77	19	80	—	75
	9.5	17	1.3	293	170	29.5	4	92	42	86
	4.5	12.5	12.8	304	189	36.5	8.0	—	39	78
	13	8	19.4	281	170	49	9	—	39	81
	17	17.0	5.0	316	177	39	27	71	44	31

facilities including grit tanks, oil interceptors and ponds for additional sedimentation, wastes were treated by flotation.

From data presented in Table 2 it is evident that removal efficiencies achieved by pressure flotation with aluminium sulfate addition are 37%–80% for SS (initial concentration = 23–100 mg/l), 57%–93% for oil substances (initial concentration = 25–70 mg/l). The COD value is being reduced by 24%–58% (COD initial = 155–442 mg/l).

The results obtained from full-scale flotation studies with addition of BPK-101 flocculant at dosages of 2 to 15 mg/l show that optimum doses of a flocculant are in the range of 5 to 10 mg/l, which are one tenth-one fifteenth as much as that for an inorganic coagulant (Table 2). Under optimum operating conditions removal efficiencies achieved by the flotation process are 71%–92% (initial concentration = 17–80 mg/l) for suspended solids, 75%–85% for oil substances (initial concentrations = 30–100 mg/l). Simultaneously the COD value is reduced by 39%–70% (initial concentration = 180–293 mg O₂/l).

While carrying out full scale studies, it has been found that moisture content of foam being produced during flotation treatment of wastes, is reduced from 94%, if aluminium sulfate is added as a coagulant, to 88%–91%, if BPK-101 flocculant is employed.

Comparative analysis of data obtained shows that petroleum refinery wastes can be treated effectively by using BPK-101 flocculant.

Introduction of chemicals through mixing and floc formation chambers ahead of flotation cell (Fig 5B) allows to achieve high degree of effluent quality (5). The addition of aluminium sulfate as a coagulating aid provides 88%–96% removal for oil substances (residual concentration is 1 to 6 mg/l). Removal efficiency for SS is 81%–93%, the COD value is reduced by 70%–77%.

Thus the results of pilot and full scale studies indicate that the use of flocculants for intensification of mechanical treatment of petroleum refinery wastes is appropriate.

Activated Sludge Enhancement: A Viable Alternative To Tertiary Carbon Adsorption

Leonard W. Crame
Texaco Inc.

Presented by:
U.V. Henderson, Texaco Inc.

Introduction

In view of the possibility of more stringent 1983 BATEA (Best Available Technology Economically Achievable) effluent guidelines,^{1,2,3,4} petroleum refiners are faced with the dilemma of an insufficient data base to determine the proper approach for making cost-effective improvements. The EPA previously proposed granular activated carbon adsorption after activated sludge treatment as BATEA technology; however, the current emphasis is to consider both effluent quality and the cost effectiveness of attaining the desired results. Two proposed approaches to BATEA technology are (1) increasing the sludge age (or mean cell residence time) of the activated sludge biomass to develop a more diverse population capable of assimilating biorefractory organics or (2) adding powdered carbon directly to activated sludge aeration basins. Both alternatives to tertiary carbon adsorption would require little capital investment and would lower operating costs.

Grutsch and Mallatt^{5,6,7,8,9,10,11} have proposed that the best refinery end-of-pipe treatment for soluble organic removal should include pH control, equalization, optimized dissolved air flotation (DAF), and high sludge age (20–50 days) activated sludge treatment. High sludge ages (SA) require mixed liquor solids levels above conventional levels (5–10 days SA). These higher levels increase solids flux and must be considered in secondary clarifier solids loadings. Also high effluent TSS, despite less frequent sludge wasting, can result in a loss of mixed liquor solids.

Grutsch and Mallatt emphasize that optimized chemically-assisted DAF pretreatment (or comparable pretreatment) reduces the colloid charge (zeta potential) to maximize partial agglomeration for efficient flotation, and reduces the organic load on the activated sludge unit (ASU). Removing colloids normally present in raw refinery wastewater allows better bioflocculation and lower effluent total suspended solids (TSS) since most refinery colloids and biosolids have repelling negative charges. The microbial population could then acclimate to the biorefractory organics by producing enzymes which reduce these to simpler biodegradable substrates. Current reports from within the petroleum industry seem to indicate some benefits for increasing SA. Other investigators¹² have reported that high SA (low food/microorganism ratio) produces poor sludge settleability.

As a result of pilot studies at the Du Pont Chambers Works, Hutton and Robertaccio¹³ were issued a U.S. patent¹⁴ for the Du Pont PACT process.¹⁵ The PACT process basically involves the addition of powdered carbon (or fuller's earth, etc.) to an ASU, usually in a range of 50–400 mg/l based on influent flow. Du Pont has reported^{16,17,18} a number of advantages of the PACT process which include:

- (1) color removal,
- (2) stability against shock loadings,
- (3) improved BOD removal,
- (4) improved refractory organic removal,
- (5) resistance to toxic substances,
- (6) improvement in hydraulic capacity,
- (7) improved nitrification (mainly in municipal wastes),
- (8) foam suppression, and
- (9) improved sludge settling and increased clarifier capacity.

A disadvantage of the PACT process is that the system can become very expensive if powdered carbon addition rates become high (hundreds of mg/l), even though powdered carbon is cheaper than granular carbon.

DeJohn and Adams^{19,20,21} have developed a considerable amount of pilot study data on activated sludge-powdered carbon systems. They report significant enhancement in studies involving refinery and petrochemical wastewaters. DeJohn and Adams explain the powdered carbon enhancement mechanism as localization and concentration of oxygen and pollutant as the result of adsorption on carbon surfaces, resulting in a more complete biooxidation. The adsorption of biorefractory organics allows a longer residence time for these components in the system. Other researchers^{22,23} have found similar improvements using activated sludge-powdered carbon systems and purpose analogous enhancement mechanisms.

Rizzo²⁴ has reported a case history of a full-scale activated sludge-powdered carbon demonstration run at the Corpus Christi, Texas, Sun Oil refinery. Results included better system stability, reduction of foaming, resistance to upset conditions, lower effluent suspended solids and clearer effluent, and improved organic removal. These improvements were achieved by maintaining only a 450-mg/l powdered carbon reactor concentration with a 10-mg/l powdered carbon dosing requirement. The shortcoming of this investigation was that a parallel control could not be run simultaneously and most improvements reported could possibly have been attributed to better clarification.

The merits of powdered carbon enhancement have been further confused with the more recent development of several types of powdered carbons with significantly different properties.

Scope of Work

1. Objective

The objective of this study was to determine if the relatively simple process changes of increased sludge age or the addition of powdered activated carbon in conventional refinery activated sludge systems can significantly enhance the removal of organic wastewater contaminants to achieve or approach the level of proposed BATEA (1983) technology more cost effectively than the addition of granular activated carbon contactors to BPCTCA (1977) technology.

2. Procedures

In Part I of this study, five completely-mixed (15 gal) ASU's were operated in parallel with identical 18-hr retention times and 300-gpd/sq ft clarifier rise rates. A sixth ASU was run as a second-stage unit with the same 18-hr retention time (Figure 1). All biological reactors were located in a temperature controlled room in an attempt to dampen influent wastewater temperature variations and control biological reactions at about 85 F.

ASU's A and F served as controls, simulating conventional refinery units with a 0.3 lb TOC/lb MLVSS-day organic loading. Separate controls were run to determine the effect of optimized pretreatment on activated sludge treatment and tertiary carbon adsorption. Equalized (24-hr) and pH-controlled refinery wastewater was pretreated by dual-media (sand-

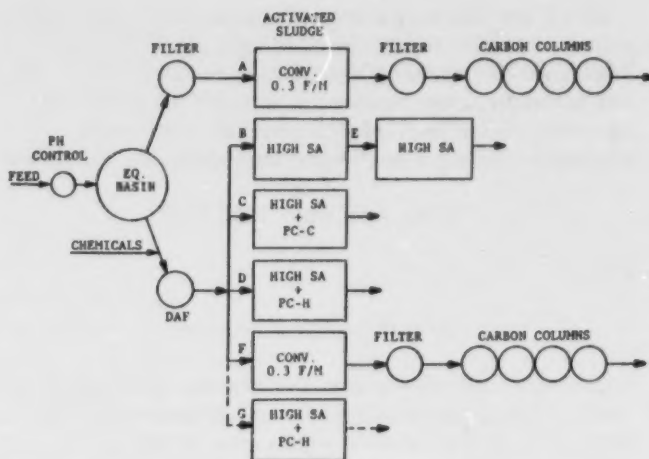


Figure 1.
Treatment Schemes.

anthracite) filtration (4.6 gpm/sq ft) and a chemically assisted DAF unit (1.5 gpm/sq ft) prior to control ASU's A and F, respectively. The optimized DAF pretreatment neutralized the negatively charged colloids, thus facilitating their removal and producing a bio-unit feed that contained essentially only soluble organics. Sodium phosphate (monobasic) was added to the filter and DAF unit effluents for a minimum TOC: phosphorus ratio of 100:2 to assure a proper nutrient level. Effluents from ASU's A and F were continuously filtered through a dual-media (sand-anthracite) tertiary filter for TSS removal before passing through a series of four granular activated carbon contactors to simulate proposed 1983 BATEA technology.

ASU's B, C, and D treated optimized DAF effluent with sludge wasting calculated for a 50-day biological SA. A commercially available, conventional-surface-area, powdered carbon²⁵ (designated PC-C) was added daily to ASU C to maintain a 500-mg/l reactor operating level. Similarly, PC-H, a high-surface-area powdered carbon,²⁶ was added to ASU D to investigate its enhancement capabilities.

ASU E was also operated at a 50-day SA treating ASU B effluent to determine if there was any benefit to ASU staging.

In Part II of this study, the second-stage ASU E was placed in parallel with other ASU's treating the DAF unit effluent as shown in Figure 1 and redesignated as ASU G. PC-H was added to ASU G to maintain a 2500-mg/l operating level while powdered carbon levels were increased in ASU C and D to 1000 mg/l.

Effluents were collected daily, Monday through Friday, as grab samples. Grab samples were taken in lieu of composites for convenience since the pilot unit treatment scheme contained significant equalization. Samples from the equalization basin, biological reactors, and carbon columns were filtered with Gelman type A/E glass fiber filters to give the soluble contaminant (TOC, COD, S=) level. Glass fiber filters were used instead of 0.45-micron filters because the solids retained on glass fiber filters define the TSS measurement. Samples were analyzed immediately after collection or were preserved until analyzed using accepted preservation methods.²⁷

All effluent data were compared after plotting values on log-normal probability papers. Single straight line data fits were determined by calculating 50th and 90th percentile values. The 50th percentile values equaled the antilog of the mean of the log values of data sets. The 90th percentile values were calculated assuming a single-tailed log-normal data distribution.

$$\ln N_{40} = \ln N_{50} + 1.282 \ln S^d$$

where

S^d is the standard deviation.

Engineering judgment was used to determine which data sets being compared appeared different and required additional statistical analyses to confirm significance of median differences. Median data values were compared to determine if they were from the same population using a paired t-test^{2H} assuming a log-normal distribution as follows:

$$\text{compute } t = \frac{\bar{d}}{\sqrt{\frac{\sum d^2 - (\sum d)^2/n}{n(n-1)}}} = \frac{\bar{d}}{\sqrt{S_d^2/n}}$$

$\bar{d}$ = mean of differences = $\sum_{i=1}^n d_i / n$ where $d_i = \ln x_i - \ln y_i$
for $i = 1, 2, 3, \dots, n$ of n data pairs

S_d = standard deviation of d_i .

The test hypothesis is that data are from the same population, therefore, their true medians are equal. This hypothesis is rejected if the calculated t-value exceeds the tabled two-tailed t-value for $n-1$ degrees of freedom for the selected (90 percent) confidence level.

Results

1. Part I - Pretreatment

The blended refinery wastewater contained excessive amounts of colloids and TSS coated with oil, complicating pretreatment. The DAF unit chemical dosages were relatively high at 40 mg/l filter alum ($Al_2(SO_4)_3 \cdot 14.3 H_2O$) and 20–40 mg/l Dearborn 431 cationic polymer. Chemical dosages were initially optimized using zeta potential titrations in conjunction with jar tests; however, only jar tests were continued since zeta potential calculations became tedious and inconsistent due to the high wastewater specific conductivity (usually 4000–8000 micromhos/cm). This salinity was primarily due to the brackish intake waters to the refinery and may have impeded chemical coagulation at lower chemical dosages as reported by Gruttsch and Mallatt.⁸

The superiority of the optimized DAF unit (operating at 1.5 gpm/sq ft) as a pretreatment system over simple sand filtration is clearly evident in the three weeks of run data represented in Figure 2.

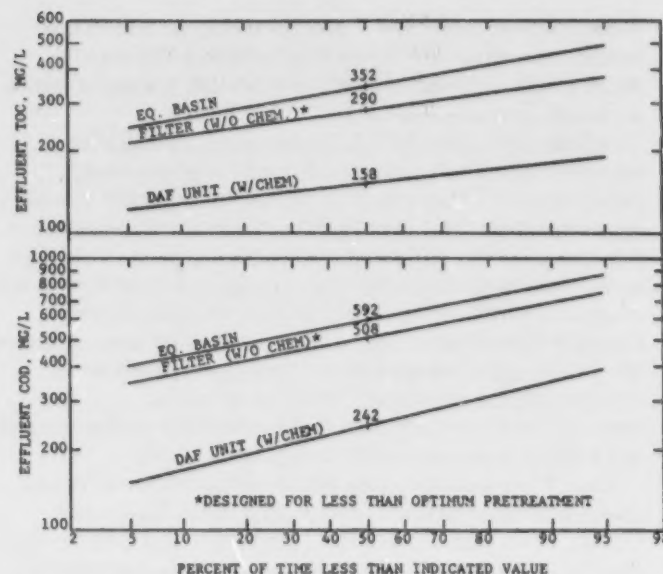


Figure 2.
Part I—TOC and COD Removal By Pretreatment.

DAF unit effluent 50th percentile TOC (158 mg/l) was 55 percent less than the 50th percentile TOC (352 mg/l) in the equalization basin influent to the DAF unit, while the sand filter gave only a 18-percent reduction. Since, at best, only a 31-percent TOC reduction could be achieved by vacuum filtration of equalization basin samples with glass fiber filters (which define TSS), the true effectiveness (55 percent reduction) of colloid and oil coagulation and removal in the chemically assisted DAF unit can be seen. The DAF unit effluent contained essentially only soluble organic contaminants.

The continuous dual-media filter (operating at 4.6 gpm/sq ft) could only manage a TOC reduction of about one-third of the DAF unit. There was no indication that a shorter run time would improve the filter effluent significantly. It appeared that due to the nature of the solids, chemical addition to the filter feed would have been required for an improved system. The purpose of the filter, however, was to produce a biological reactor feed with characteristics comparable to DAF treatment without chemicals. It was observed, on occasions, that DAF pretreatment was very poor when chemical feed pumps failed.

Figure 2 illustrates COD removal by both pretreatment systems employed and again demonstrates the effectiveness of optimized DAF treatment. As in subsequent graphs, the data points are not shown to avoid congestion of data.

Fiftieth percentile oil and grease values during Part I of this study were 101, 70, and 16 mg/l for the equalization basin, filter effluent and DAF unit effluent, respectively. The equalization basin 50th percentile TSS level of 78.0 mg/l was reduced to 57.5 mg/l by the filter and to 19.0 mg/l by the DAF unit. A portion of the TSS in the DAF unit effluent was due to biological growth rather than influent solids. It is possible that part of the organics reduction through the DAF unit was the result of biological activity which could also occur in full-scale systems.

2. Part I - Activated Sludge Performance

TOC and COD (filtered) effluent variability plots for pilot-scale 18-hr retention ASU's are compared in Figure 3. These results are from the initial 3-week data run.

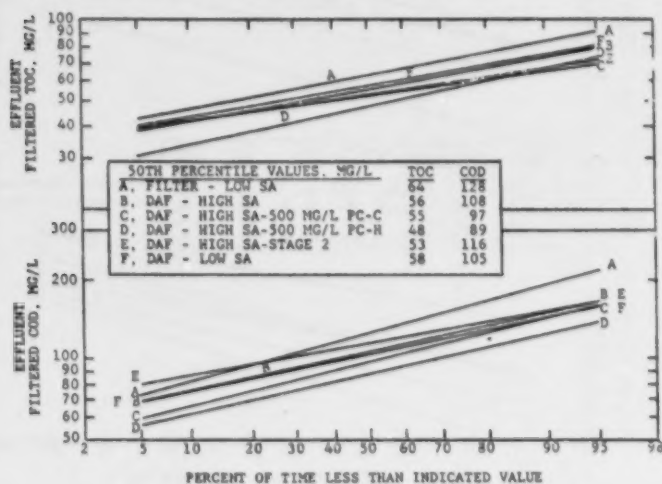


Figure 3.
Part I—Activated Sludge TOC and COD Distributions.

Control ASU F produced a better effluent than control ASU A, both operating at equal 0.3 lb TOC/lb MLVSS-day (F/M) loadings. MLVSS levels in ASU A averaged 1,148 mg/l, about twice that of ASU F due to a twofold increase in feed TOC. Considering both TOC and COD removal, ASU B, C, E, and F did not show any significant overall difference in performance. Fiftieth percentile TOC values ranged from 53–58 mg/l while COD values were 97–116 mg/l as shown in Figure 3. Sludge age was not a controlling performance variable as ASU B (50-day SA) and ASU F (about 10-day SA) differed greatly in solids retention time with average MLSS levels of 1,621 mg/l and 816 mg/l, respectively. Chemically assisted pretreatment for removal of colloids and oil had the most significant effect on organics removal. The high-surface-area powdered carbon (designated PC-H) significantly enhanced organic removal in ASU D, with a 50-day SA and a 500-mg/l PC-H operating level. Enhancement was not evident in ASU C containing the conventional-surface-area powdered activated carbon (designated PC-C). Powdered carbon addition increased the average ASU C MLSS level to 1,885 mg/l with ASU D averaging 1,976 mg/l.

Since a marginal enhancement occurred with the addition of PC-H at a 500-mg/l level, the scope of this investigation was expanded to evaluate powdered activated carbon addition at a 1000-mg/l level and only PC-H at approximately 2500 mg/l. This would give a greater overview of the enhancement capabilities of powdered carbon, especially the highly active PC-H. ASU E was taken out of service since it was only succeeding in lysing biological cells as a second stage following ASU B. The reactor was placed in parallel with other units being fed by the DAF unit and redesignated ASU G. The SA maintained at 50 days and PC-H was built up to a reactor level of about 2500 mg/l for Part II of this study.

3. Part I - Granular Carbon Adsorption

Granular carbon Series A, treating ASU A effluent, exhausted two 130-gram carbon beds during 17 days of a 3.4-gpm/sq ft hydraulic loading in Part I. A 20-mg/l soluble (filtered) TOC and a 44-mg/l soluble COD effluent (50th percentile, Figure 4) was produced with 0.10 and 0.09-g TOC/g carbon accumulative loadings at exhaustion. Carbon Series F, treating ASU F effluent, reduced the 50th percentile effluent soluble TOC and COD to 23 mg/l and 40 mg/l, respectively. Because of the relatively few data points used to establish Figure 4, there is little significance in the difference between carbon series A and F 50th percentile values. A single carbon bed was exhausted to a 0.12-g TOC/g carbon loading. TOC loadings of carbon columns in Series A were comparable to an average of 0.11 g TOC/g carbon reported for the granular carbon during the four previous exhaustions prior to each regeneration.

Granular carbon effluents were of substantially better quality than all biological unit effluents. The 50th percentile soluble TOC and COD reductions in carbon Series A were 44 mg/l and 84 mg/l, respectively, whereas carbon Series F accounted for a 50th percentile 35-mg/l soluble TOC and 65-mg/l soluble COD reduction.

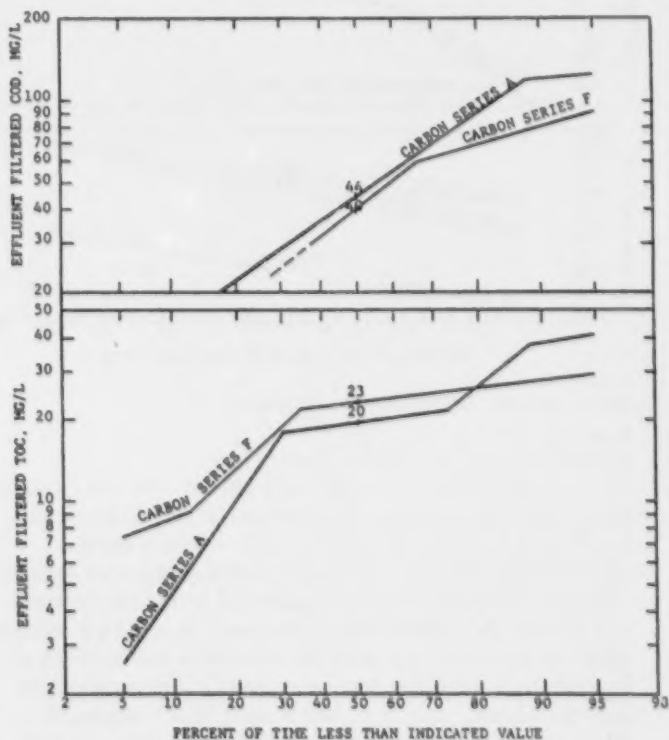


Figure 4.
Part I—Granular Carbon Column TOC and COD Distributions.

4. Part II - Pretreatment

Pretreatment by filtration and chemically assisted DAF treatment continued as in Part I of this study. Again, using dosages of 40-mg/l filter alum and 20–40 mg/l Dearborn 431, optimized DAF pretreatment reduced the equalization basin TOC and COD by more than 50 percent as shown in Figure 5. Filtration could only remove gross quantities of oil and solids without preliminary chemical coagulation. Although equalization basin, filter, and DAF unit effluent 50th percentile TOC and COD concentrations were approximately equal to those experienced in Part I of this study, there existed a greater degree of variability in Part II. A contributing variability factor was the rainfall dilution of refinery wastewater streams as an average of 0.21 in./day of rain fell during Part II compared with 0.06 in./day during Part I.

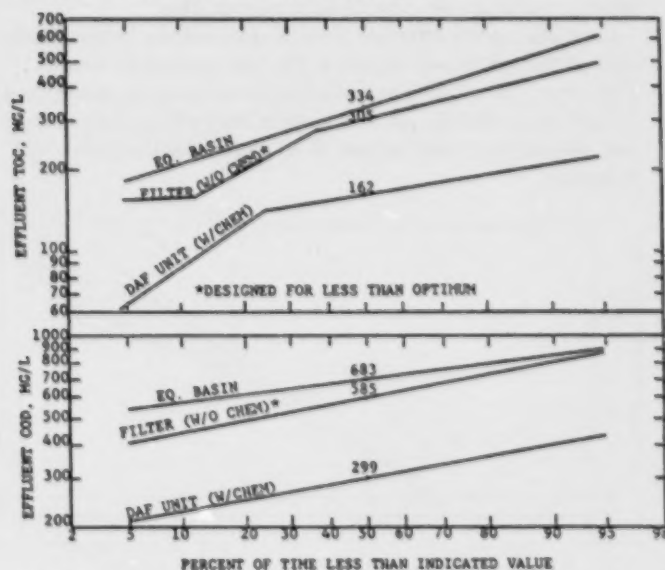


Figure 5.
Part II—TOC and COD Removal by Pretreatment.

5. Part II - Activated Sludge Performance

The effluent quality for Part II, basis filtered TOC and COD, is given in effluent frequency distributions, Figure 6, for the six-week run period. Control ASU A (F/M = 0.3), without optimized pretreatment, continued producing the most inferior effluent and experienced three upsets due to the development of a filamentous bulking sludge. The unit was restarted on each upset occasion with new seed and allowed to acclimate for a few days before effluent data were used for comparison with parallel systems. ASU B, C, and F, as in Part I, produced nearly equivalent effluents in terms of filtered TOC and COD with neither high SA (50 days) nor 1000 mg/l PC-C enhancing biological treatment. PC-H added to ASU D and G at levels of 1000 and 2500 mg/l, respectively, reduced TOC and COD substantially. Compared with high SA control ASU B, 50th percentile TOC was reduced an additional 10 mg/l and 22 mg/l in reactors D and G, respectively. COD 50th percentile reductions below reactor B were 22 mg/l for ASU D (1000 mg/l PC-H) and 39 mg/l for ASU G (2500 mg/l PC-H). The ASU G run time was abbreviated, however, due to the time required

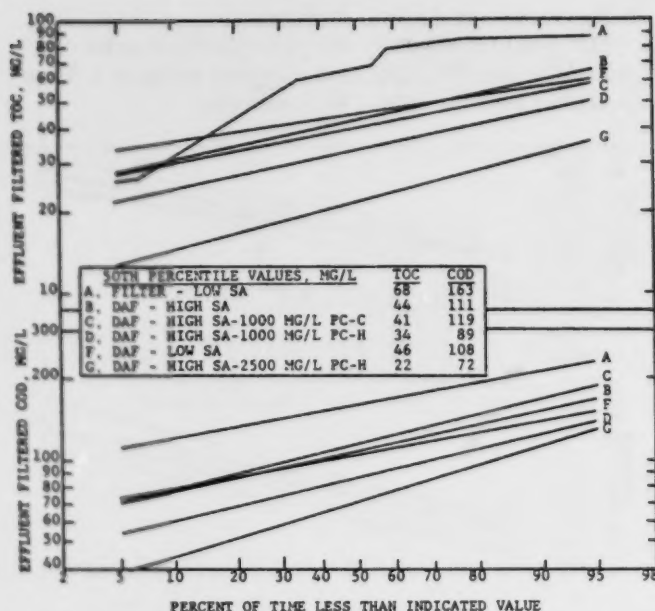


Figure 6.
Part II—Activated Sludge TOC and COD Distributions.

for acclimation at the higher PC-H level. As in Part I of this study, it was observed that as powdered carbon levels were suddenly increased in ASU C, D, and G, performance was exceptionally good for a short period of time.

Phenols feed concentrations were higher in Part II of this investigation as 90th percentile values reached 18 mg/l, compared with 8.5 mg/l in Part I. ASU D (see Table I) and G, containing PC-H, provided the best phenols removal with 50th percentile phenols levels of 0.05 mg/l and 0.04 mg/l, respectively. This was slightly lower than the high SA control ASU B (0.06 mg/l) and low SA control ASU F (0.07 mg/l). Although the lack of optimized pretreatment produced higher 50th percentile phenols levels (0.11 mg/l) in ASU A, even poorer reductions were experienced with ASU C as in Part I. Similar results were obtained in Part I. An occasional high phenols value was measured in the effluents of ASU D and G but not with the consistency or magnitude of ASU C.

Effluent oil and grease values, included in Table I, illustrate the significance of removing most of the oil and grease before biological treatment. The 18 mg/l 50th percentile oil and grease effluent level of ASU A greatly exceeded the concentration of 5 mg/l, or less, discharged from reactors receiving optimized pretreatment. The addition of PC-H to ASU D and G gave slight oil and grease improvement with SA alone not being in enhancement factor.

Effluent TSS levels were high in ASU A at a 50th percentile level of 86 mg/l. TSS increased to more than 150 mg/l when filamentous sludge bulking occurred. However, ASU's with DAF pretreatment produced a more settleable sludge. The high SA control ASU B had a significantly higher effluent TSS level than the lower SA control ASU F, but the high SA could be maintained. ASU C and D experienced effluent TSS levels less than control ASU B despite higher reactor solids due to

Table 1
Part II—Effluent Summary
(ALL VALUES MG/L)

EFFLUENT SAMPLE	PHENOLS PERCENTILE		OIL & GREASE PERCENTILE		TSS PERCENTILE		AMMONIA PERCENTILE	
	50TH	90TH	50TH	90TH	50TH	90TH	50TH	90TH
EQ EASIN	7.3	18.0	108	191	64.0	119	20.9	27.2
FILTER	—	—	69	130	34.0	74.0	—	—
DAF UNIT	—	—	14	19	13.0	21.0	—	—
ASU A	0.11	0.16	18	38	86.0	149	11.5	20.0
ASU B	0.06	0.14	5	7	27.5	41.0	3.9	9.2
ASU C	0.15	0.38	3	9	23.0	77.0	3.3	5.4
ASU D	0.05	0.20	< 3	5	18.0	57.0	3.1	4.8
ASU G	0.04	0.13	< 3	3	22.0	44.0	3.1	4.4
ASU F	0.07	0.17	4	7	8.4	28.0	2.3	5.4
CARBON COL (SERIES A)	0.04	4.8	< 3	6	—	—	—	—
CARBON COL. (SERIES F)	0.02	0.08	< 3	4	—	—	—	—

Table 2
Part II—Sludge Data

AVERAGE VALUE	A	B	ACTIVATED SLUDGE UNIT		F	G
			C	D		
NOMINAL LOADING	F/M = 0.3	50-DAY SA	50-DAY SA	50-DAY SA	F/M = 0.3	50-DAY SA
ACTUAL LOADING	F/M = 0.3	39-DAY SA	42-DAY SA	44-DAY SA	F/M = 0.3	56-DAY SA
MLSS, MG/L	1.487	1.892	2.728	2.720	745	4,096
MLVSS, MG/L	1.302	1.562	2.269	2.416	689	3,898
PC, MG/L	0	0	1.000 ^a	1.000 ^b	0	2.500 ^b
% VSS	88	83	83	89	92	95
OXYGEN UPTAKE,						
LB O ₂ /LB COD REM	0.40	0.68	0.71	0.49	0.61	0.47
MG/L-MIN	0.16	0.12	0.12	0.11	0.11	0.10
SVI, ML/G	95	64	41	43	91	30
SETTLING VELOCITY, FT/ MIN	0.17	0.34	0.38	0.38	N/A ^c	0.39
BIOMASS PRODUCTION RATE ^d	0.22	0.16	0.12	0.11	0.19	0.08
TOTAL PRODUCTION RATE ^e	0.25	0.19	0.17	0.14	0.21	0.09

^a CONVENTIONAL-SURFACE-AREA.

^b HIGH-SURFACE-AREA.

^c DISCRETE SETTLING.

^d LB VSS/LB COD REMOVED.

^e LB TSS/LB COD REMOVED (INCLUDES CARBON).

powdered carbon. No effluent TSS increase was observed in ASU G due to the higher (2500 mg/l) PC-H level.

Ammonia nitrogen removal in system A was less than the 80 percent achieved in the systems with optimized pretreatment. The organic loading was higher and the sludge age was less than in other systems. The factors controlling the degree of nitrogen removal were not investigated. Nitrification during Part II was not as complete as that obtained in Part I.

Sludge Characteristics and production rates are summarized in Table 2 for all ASU's. As expected, ASU A had the highest measured oxygen uptake averaging 0.16 mg oxygen/l-min due to a higher influent organic concentration. Oxygen consumption averaged 0.10–0.12 mg oxygen/l-min in other ASU mixed liquors, but a relationship of increased oxygen demand and enhanced biological treatment did not exist. The sludge volume index (SVI), a measure of sludge compactability, significantly improved with SA and powdered carbon addition. Sludge settling velocities were exceptionally high with the worst rate

(ASU A) being 0.17 ft/min corresponding to a 1830-gpd/sq ft clarifier rise rate. Other mixed liquors settled with zone settling velocities of 0.34–0.39 ft/min. The average MLSS concentration of 745 mg/l in ASU F was too low for zone settling to occur. One of the most surprising results of powdered carbon addition was that less biomass was produced than in control systems. ASU G produced an average of 0.08 lb biomass/lb COD removed compared with control rates of 0.22 for ASU A and 0.19 for ASU F. PC-H was more effective than PC-C at reducing biomass production rates at the same SA. The total sludge production of activated sludge powdered carbon systems was not much higher than controls, due to lower biological sludge production rates.

Powdered carbon inventories and makeup requirements for ASU's are summarized in Table 3 for Parts I and II of this study. PC-C losses were slightly higher than PC-H but still reasonably close to 2 percent per day. Since biological sludge was wasted at a rate of 2 percent per day in high SA reactors,

Table 3
Powdered Carbon (PC) Requirements

ASU-PART	PC LEVEL (MG/L)	PC TYPE	PC INVENTORY (G)	ACG PC LOSS (G/DAY)	PC MAKEUP (%)
C-I	500	PC-C	28.4	0.68	2.4
D-I	500	PC-H	28.4	0.56	2.0
C-II	1,000	PC-C	56.7	1.50	2.6
D-II	1,000	PC-H	56.7	1.12	2.0
G-II	2,500	PC-H	141.9	2.21	1.6

it is a fairly good assumption that powdered carbon lost in effluents was in the same proportion to biological sludge as in the mixed liquor. Thus both biological and powdered carbon SA may be assumed to be equal for simplification of powdered carbon daily makeup requirements. The powdered carbons must be wetted to prevent loss of floating carbon in the clarifier. This was accomplished by boiling the carbon slurry in this study. Vacuum degassing could also be used.

Another observation made during Part II was that activated sludge-powdered carbon systems significantly reduced aeration basin foaming compared with control systems. Foaming in ASU aeration basins was not a problem but did occur occasionally.

6. Part II - Granular Carbon Adsorption

A single granular carbon bed was exhausted from carbon Series A with an accumulative organic loading of 0.15 g TOC/g carbon during Part II. The data include three short runs. The first two carbon beds required backwashing almost daily due to high TSS levels which could not be continuously removed by dual-media filtration. Fiftieth percentile effluent soluble TOC was 30 mg/l (see Figure 7) for a reduction of 38 mg/l from ASU A. ASU A 50th percentile soluble COD was reduced by 84 mg/l to 79 mg/l. Although phenols levels were generally low (50th percentile of 0.04 mg/l) a few very high effluent phenols levels were detected in carbon Series A giving a 90th percentile phenols value of 4.8 mg/l (Table 1). Phenols must have been adsorbed, concentrated, and then eluted in slugs from the carbon beds to achieve such a high level. Effluent oil and grease levels remained low with 50th percentile values less than 3 mg/l.

Carbon Series F exhausted a single carbon bed to an accumulative organic loading of 0.13 g TOC/g carbon while surpassing the performance of carbon Series A. The 50th percentile soluble TOC was significantly lower at 18 mg/l for a 28 mg/l reduction (Figure 7) from ASU F. Fiftieth percentile soluble effluent COD was 64 mg/l for a 44 mg/l reduction. Phenols levels were extremely low at 0.02 mg/l (50th percentile) and no sudden loss of adsorbed phenols was detected during most of the Part II data run (Table 1). Oil and grease effluent levels (50th percentile) were again less than 3 mg/l.

The lower dashed lines in Figure 7 represent the performance of ASU G, the best of the activated sludge-powdered carbon reactors. ASU G produced an effluent superior to carbon Series A and approached the quality of carbon Series F. The powdered carbon enhancement removed about 85 percent of the soluble TOC adsorbed on carbon Series F and about 60 percent of the COD based on 50th percentile

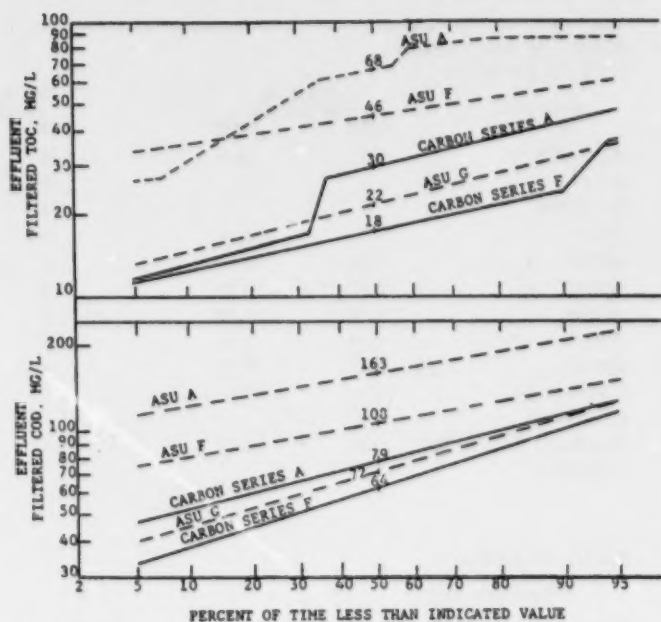


Figure 7.
Part II—Granular Carbon TOC and COD Distributions.

effluent values. The 2,500 mg/l PC-H operating level in ASU G significantly reduced effluent color to a level comparable with granular carbon effluent color.

7. Economics

Although unequal in overall performance, a high SA activated sludge-powdered carbon system (ASU G, 72 mg/l COD) approached the level of granular carbon adsorption (carbon Series F, 64 mg/l COD) to within 8 mg/l COD at the 50th percentile point. Both systems would require extensive pretreatment and tertiary suspended solids removal. All other process components being essentially equal, daily carbon usage costs were estimated for theoretical plant flows of 1-5 MM gpd.

The cost of virgin powdered carbon (PC-H or PC-C) was estimated at \$0.30/lb and it was assumed that wasted carbon would be thrown away. To calculate the equivalent powdered carbon dosage required for an 18-hr retention ASU it was assumed a 50-day SA would be maintained, giving an average 2 percent powdered carbon makeup. This was the equivalent of a 37.1 mg/l powdered carbon addition rate based on influent flow. A powdered carbon feeder and storage facilities were included in powdered carbon costs using Du Pont economics¹⁶ and applying the 0.6 rule. It was assumed that the powdered carbon feeder could handle a 50 mg/l addition rate.

Regenerated granular carbon adsorption costs were estimated, using Brown and Root, Inc. economics,¹⁹ and converted to 1977 dollars. Daily granular carbon costs were estimated using 17.2 percent of the fixed investment for operating and maintenance cost and 17.7 percent for depreciation. The total daily costs for powdered carbon were estimated using the same percentage allowances.

Daily estimated carbon costs are shown in Figure 8 for theoretical flows of 1-5 MM gpd by scaling up ASU G and

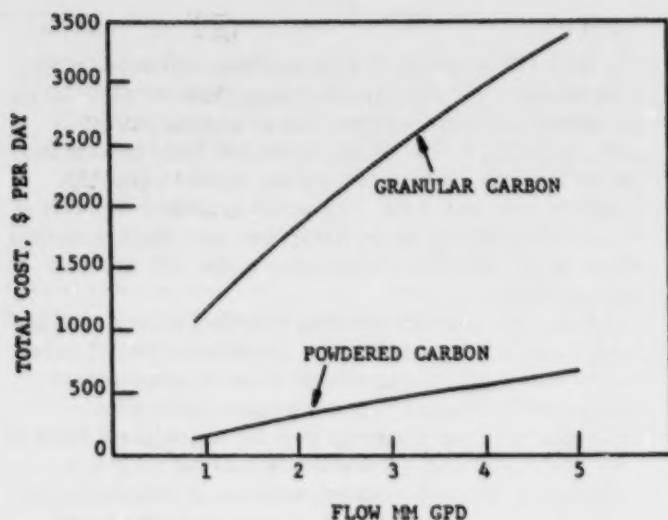


Figure 8.
Comparison of Estimated Carbon Costs.

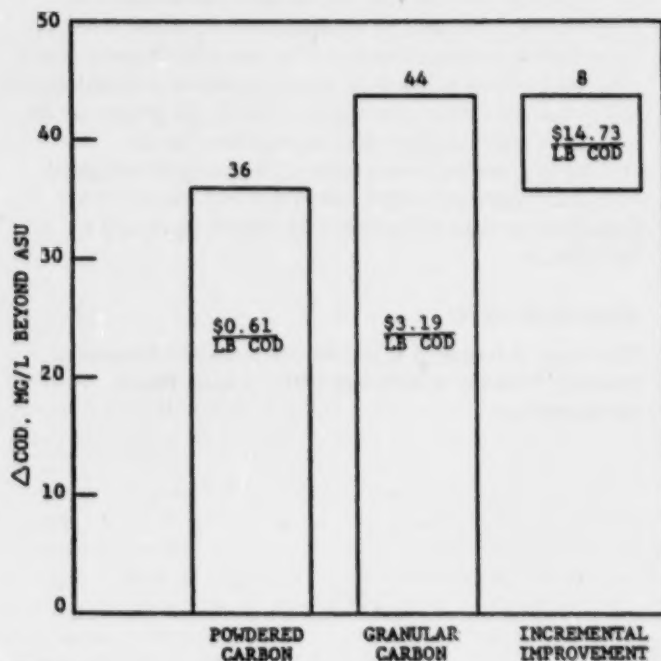


Figure 9.
Estimated Effective Carbon Cost at 1 MM GPD.

carbon Series F carbon requirements. The cost effectiveness of the relatively simple process change of adding powdered activated carbon to the activated sludge process can be clearly seen. Estimated daily cost savings would range from \$987/day at 1 MM gpd flow to \$2750/day at 5 MM gpd using high-surface-area powdered carbon (PC-H) addition rather than granular carbon adsorption. The incremental cost would be about \$14.73 per pound of COD at 1 MM gpd (see Figure 9).

Discussion

1. Increasing Sludge Age (SA)

Contrary to conventional activated sludge design techniques, the increased SA did not result in sludge deflocculation, higher SVI, and high effluent TSS. With the exception of a few days, the high SA control ASU B easily achieved a high SA as a result of good pretreatment as proposed by Gruttsch and Mallatt.^{10,11} However, no enhanced performance was measured at the high SA nor in the two-stage system with both reactors at a high SA in Part I. Possibly more emphasis should be placed on the benefits of optimized pretreatment than on increased SA as parallel activated sludge systems at about the same SA ($F/M = 0.3$) were vastly different in performance at contrasting degrees of pretreatment.

Increasing SA gave a reduction in biological solids production as the conventional F/M control ASU F produced 0.19 lb VSS/lb COD removed compared with 0.16 for high SA control ASU B. This sludge production was not quite as significant as it would have been if ASU F had operated at 5–10 days SA where many conventional ASU's operate instead of about 14 days. Any reduction of biological solids production would help lower sludge treatment and disposal costs.

The high effluent 50th percentile ammonia level of ASU A (11.5 mg/l) in Part II was probably the result of upset conditions which resulted from filamentous sludge bulking causing the loss of biomass. The calculated 10-day SA of ASU A was only slightly less than ASU F (14 days) which produced a 50th percentile ammonia level of 2.3 mg/l in Part II. Although increasing SA generally does improve nitrification, no conclusions could be drawn as to its effect in this study. The conventional ASU F had already produced an effluent that was about 90 percent nitrified.

2. Activated Carbon Enhancement Mechanism

A 0.59-g TOC/g carbon loading was calculated in ASU G while operating with a 2500 mg/l PC-H level. This extremely high "apparent" TOC loading, as explained by Flynn,¹⁸ may be the result of continuous adsorption of slowly biodegraded organics which are "biologically regenerated" from the carbon many times over the biological and carbon SA. "Apparent" TOC loadings therefore increase with higher SA, optimizing the use of powdered carbon, until the carbon becomes loaded with completely biorefractory organics. This explanation of an "apparent" loading or enhancement mechanism appears logical; however, oxygen uptake and biological sludge production data presented here negate biological regeneration in this study. ASU G not only had comparable oxygen uptake measurements with control ASU B, but it produced about 50 percent less biological solids. This implies that the actual enhancement may have been predominantly due to adsorption on the high PC-H surface area. Considering that PC-H had approximately five times the surface area of conventional powdered carbons, such as PC-C, the expression of the TOC loading as 0.12 g TOC/500 sq m of surface area would be more reasonable.

DeJohn^{19,30} explains that granular carbon columns are sometimes undersized because the designer uses virgin carbon and assumes that regenerated carbon will have the same activity. The thermal regeneration process will enlarge some carbon pores reducing the surface area and decreasing the adsorption of small molecules which are not so strongly adsorbed on larger pores. Assuming that many small molecules require small powdered carbon pores for moderately strong adsorption, PC-H may have been more effective than PC-C because of pore size distribution, provided that the normally biorefractory refinery organics were small molecules.

The mechanism of powdered carbon enhancement of the activated sludge process was not defined in this study and needs further investigation in Phase II. Target SA's of the activated sludge-powdered carbon systems were 50 days. Ideally, systems should be operated for periods of several SA's to insure that equilibrium conditions have been reached and that the low (2 percent) daily powdered carbon makeup rate will continue to give consistent results.

The selection of the best powdered carbon for a particular activated sludge enhancement is not a simple task since powdered carbons vary in their adsorptivity. Carbon isotherms performed on a refinery wastewater would exhibit a wide variability and require a statistical analysis to select the best powdered carbon. Isotherms would have to be performed on the activated sludge effluent (as in Phase II of this study) to determine enhancement strictly due to adsorption.

The powdered activated carbon (PC-H) utilized with very good enhancement results is not, as of yet, commercially available. Because of the relatively high cost of granular carbon adsorption, other powdered carbons at similar and higher operating levels would probably offer a significant improvement in activated sludge performance and remain more cost effective than granular carbon.

3. Granular Carbon Adsorption

Granular carbon adsorption data indicate that the quality of end-of-pipe refinery wastewater treatment depends on optimization of each treatment step from primary to tertiary treatment. The use of equilibrium or regenerated granular carbon in pilot studies will provide a more realistic data base, recognizing that economics would favor regeneration for many potential users.

The classical approach^{31,32,33,34} for handling carbon adsorption data to establish breakthrough curves was virtually useless in this study because it assumes the carbon column influent has a single adsorbate. In the calculation of accumulated TOC loadings at apparent breakthrough of carbon columns there were several instances where organics were eluted in slugs from carbons in both series. At times, phenols were two orders of magnitude higher than normal. This phenomenon is a very real problem and must be considered when establishing stringent effluent discharge guidelines for industry. Even the best available technology, disregarding economics, has its limitations.

Summary

The EPA 1983 guidelines for the petroleum refining industry have assumed that 1977-type technology must be upgraded by the addition of costly systems, such as granular activated carbon adsorption. The results of this API study indicate that, should the EPA adhere to the granular carbon technology originally proposed, it may be possible to achieve this level of treatment technology by the much more cost-effective method of adding powdered activated carbon to the 1977 activated sludge system.

Process modifications including optimized pretreatment and the addition of a high-surface-area powdered activated carbon can be used to produce an effluent which is comparable in quality to that obtained by granular carbon adsorption. Increasing activated sludge age from the conventional mode of operation (about 10 days) to about 50 days did not give a significant system improvement; however, in conjunction with powdered carbon addition, high sludge age allowed higher equilibrium reactor concentrations (2500 mg/l) at low (2 percent) carbon makeup rates. This benefit has been demonstrated with the high-surface-area carbon and it is possible that it can also be obtained with increased levels of conventional powdered carbon. The cost-effectiveness of any powdered carbon will depend on the wastewater characteristics and powdered carbon adsorptivity, which was greater for the high-surface-area carbon (2462 sq m/g) than for the conventional-surface-area carbon (550 sq m/g) investigated here. Even granular carbon adsorption was found to have limitations as slugs of phenols were eluted, on occasion, into the effluent.

Acknowledgements

This study was funded in part by the American Petroleum Institute, Division of Refining, CREC Liquid Waste Subcommittee.

REFERENCES

- Environmental Protection Agency. "Petroleum Refining Point Source Category Effluent Guidelines and Standards." *Federal Register*, Vol 38 (240) 34542 (December 14, 1973).
- Environmental Protection Agency. "Petroleum Refinery Point Source Category Effluent Guidelines and Standards." *Federal Register*, Vol 39 (91) 16560 (May 9, 1975).
- Environmental Protection Agency. "Petroleum Refining Point Source Category Effluent Guidelines and Standards." *Federal Register*, Vol 40 (98) 21951 (May 20, 1975).
- Jones Associates. "Effluent Limitations in the Petroleum Refining Industry." Vol 1B. Prepared for the Office of General Counsel, American Petroleum Institute (January, 1976).
- J. F. Grutsch and R. C. Mallatt. "Optimize the Effluent System—Part 1: Activated Sludge Process." *Hydrocarbon Processing*, Vol 55 (3) 105 (1976).
- J. F. Grutsch and R. C. Mallatt. "Optimize the Effluent System—Part 2: Intermediate Treatment." *Hydrocarbon Processing*, Vol 55 (4) 213 (1976).
- J. F. Grutsch and R. C. Mallatt. "Optimize the Effluent System—Part 3: Electrochemistry of Destabilization." *Hydrocarbon Processing*, Vol 55 (5) 221 (1976).
- J. F. Grutsch and R. C. Mallatt. "Optimize the Effluent System—Part 4: Approach to Chemical Treatment." *Hydrocarbon Processing*, Vol 55 (6) 115 (1976).
- J. F. Grutsch and R. C. Mallatt. "Optimize the Effluent System—Part 5: Multimedia Filters." *Hydrocarbon Processing*, Vol 55 (7) 113 (1976).
- J. F. Grutsch and R. C. Mallatt. "Optimize the Effluent System—Part 6: Biochemistry of Activated Sludge Process." *Hydrocarbon Processing*, Vol 55 (8) 137 (1976).
- J. F. Grutsch and R. C. Mallatt. "A New Perspective on the Role of the Activated Sludge Process and Ancillary Facilities." Presented at Joint EPA-API-NPRA-TU Open Forum on Management of Petroleum Refinery Wastewaters, Tulsa, Oklahoma (January 26-29, 1976).
- D. L. Ford and W. W. Eckenfelder, Jr. "Effect of Process Variables on Sludge Floc Formation and Settling Characteristics." *Journal Water Pollution Control Federation*, Vol 39 (11) 1850 (1969).
- G. Grulich, D. G. Hutton, F. L. Robertaccio, and H. L. Glotzer. "Treatment of Organic Chemicals Plant Wastewater with the Du Pont PACT Process." Presented at AIChE National Meeting (February, 1972).
- D. G. Hutton and F. L. Robertaccio. U. S. Patent 3,904,518 (September 9, 1975).
- E. I. Du Pont DeNemours and Company. "Du Pont PACT Process." Technical Bulletin.
- B. P. Flynn and L. T. Barry. "Finding a Home for the Carbon: Aerator (Powdered) or Column (Granular)." Proceedings of the 31st Annual Purdue Waste Conference (May 5, 1976).
- B. P. Flynn. "A Methodology for Comparing Powdered Activated Carbons for Activated Sludge." Presented at 168th National Meeting, ACS, Div. of Petroleum Chemistry, Symposium on Disposal of Wastes from Petroleum and Petrochemical Refineries (September 13, 1974).
- B. P. Flynn, F. L. Robertaccio, and L. T. Barry. "Truth or Consequences: Biological Fouling and Other Considerations in the Powdered Activated Carbon—Activated Sludge System." Presented at 31st Annual Purdue Waste Conference (May 5, 1976).
- P. B. DeJohn and A. D. Adams. "Treatment of Oil Refining Wastewaters with Granular and Powdered Activated Carbon." Proceedings of 30th Annual Purdue Industrial Waste Conference (May 6, 1975).
- A. D. Adams. "Powdered Carbon: Is It Really That Good?." *Water and Wastes Engineering*, Vol 11 (3) B-8 (1974).
- P. B. DeJohn and A. D. Adams. "Activated Carbon Improves Wastewater Treatment." *Hydrocarbon Processing*, Vol 54 (10) 104 (1975).
- A. B. Scaramelli and F. A. DiGiano. "Upgrading the Activated Sludge System by Addition of Powdered Carbon." *Water and Sewage Works*, Vol 120 (9) 90 (1973).
- A. E. Perrotti and C. A. Rodman. "Enhancement of Biological Waste Treatment by Activated Carbon." *Chemical Engineering Progress*, Vol 69 (11) 63 (1973).
- J. A. Rizzo. "Case History: Use of Powdered Activated Carbon in an Activated Sludge System." Presented at Joint EPA-API-NPRA-TU Open Forum on Management of Petroleum Refinery Wastewaters (January 26-29, 1976).
- ICI United States Inc.. "Powdered Hydrodarco Activated Carbons Improve Activated Sludge Treatment." Product Bulletin PC-4 (October, 1974).
- Amoco Research Corporation. Amoco Active Carbon Grade PX-21 Product Information Sheet (May, 1976).
- APHA. *Standard Methods for the Examination of Water and Wastewater*, 13th Ed., New York, New York (1971).
- H. E. Klugh. *Statistics: The Essentials for Research*, 2nd Ed., John Wiley & Sons, Inc., New York, New York (1974).
- Brown and Root, Inc.. "Economics of Refinery Wastewater Treatment." American Petroleum Institute Publication No. 4199 (1973).
- P. B. DeJohn. "Carbon from Lignite or Coal: Which is Better?." *Chemical Engineering*, Vol 82 (9) 113 (1975).
- Metcalf and Eddy, Inc.. *Wastewater Engineering*, McGraw-Hill, New York, New York (1972).
- W. W. Eckenfelder, Jr.. *Industrial Water Pollution Control*, McGraw-Hill, New York, New York (1966).
- H. J. Fornwalt and R. A. Hutchins. "Purifying Liquids with Activated Carbon." *Chemical Engineering*, Vol 73 (8) 1976 (1966).
- J. L. Rizzo and A. R. Shepherd. "Treating Industrial Wastewater With Activated Carbon." *Chemical Engineering*, Vol 84 (1) 95 (1977).

Electrochemical Treatment of Industrial Wastewaters

V. E. Genkin., A. N. Belevtsev

The growth of various industries results in the increase in volumes of industrial wastewater discharges and kinds of chemical substances, entering surface water supplies.

Biological methods widely applied to many types of wastewaters are generally impractical or don't provide the necessary quality of treatment of wastes containing bio-resistant substances. These facilities are large in size and require high capital investment.

Therefore, in recent years, combined treatment methods have been finding increased use: physical-chemical treatment with subsequent biological; physical-chemical process employed as tertiary treatment after biological treatment. Flowsheets of treatment facilities using physical-chemical methods alone are also being developed.

Physical-chemical treatment processes with chemicals addition often involve use of high chemical doses and cause the secondary pollution of liquids, that is, increase salt concentration. Therefore, during recent years wastewater treatment without addition of chemicals is becoming popular.

The development and the implementation of electrochemical methods is an advanced trend in the technology of wastewater treatment. The methods, in a number of cases, permit to recover valuable products, to simplify flowsheets and operation of treatment facilities, to provide control of their operation and to reduce area requirements.

Electrochemical methods usually don't lead to increase in salt content of treated effluents and, in many cases, allow to avoid sludge formation or to reduce substantially the volume of sludge produced.

While treating wastewaters by the action of a direct current, a number of processes take place: anodic oxidation and cathodic reduction of impurities present in wastewaters; solution of metallic anodes; discharge and coagulation of colloidal particles; electrophoresis; the passage of ions through semi-permeable membranes; flotation of solid particles by gas bubbles produced on electrodes; precipitation of metallic ions on cathod; regeneration and concentration of acids and alkalies; desalination of water and other electrochemical and chemical processes.

At the present time there are three main directions in the development of electrochemical treatment processes applied to wastewaters, containing various impurities:

- 1) Removal of dissolved impurities (mostly organic matter) from waste effluents in the form of non-toxic (or less toxic) and, in some cases, water insoluble products as a result of anodic oxidation and cathodic reduction.
- 2) Removal of dissolved impurities (mainly inorganic matter) from wastewaters by electrodialysis, simultaneously utilizing recovered products.
- 3) Removal of dissolved and finely divided in dispersed state (including emulsified) insoluble impurities (both organic and inorganic) by electrocoagulation methods (wastewaters are electrolyzed using soluble iron and aluminum anodes to thereby form water-insoluble precipitates) and electroflotation process (electrolytically insoluble anodes may be used for removal of dispersed matter).

All three given above trends are being under development in the USSR.

Anodic oxidation and cathodic reduction of impurities present in wastewaters.

Electrochemical methods resulting in the decomposition of organic compounds may be applied to relatively concentrated wastewaters discharged in small volumes to local plants.

These methods are finding use because of the absence of biological treatment facilities at local plants as well as the presence of non-biodegradable substances in waste streams.

Due to high consumption of energy the methods may be applied only when other methods either are not feasible or hardly economic.

Wastewaters are electrolyzed using electrolytically insoluble anodes (graphite carbon, magnetite, dioxides of lead, manganese and ruthenium deposited on titanium substrate) at relatively high current densities in electrolysis units operating with or without diaphragm.

Destruction of molecules of various organic materials resulting from oxidation at the anode by the action of current, is often accomplished with their complete decomposition, the products of which are carbonic acid, water, ammonia and other products. In some instances, anodic oxidation of organic or inorganic compounds results in the formation of more simple, non-toxic or less toxic, bio-oxidizable products (e.g. at the anode phenols are oxidized to maleic acids, cyanides to cyanates, sulfides to sulfates and so on).

More recently, electrochemical methods have been developed for the removal of dissolved impurities (cyanides, rhodanides, nitro-compounds, amines, alcohols, aldehydes, ketones, azo dyes, sulfides, mercaptans, anthraquinone derivatives and others) from waste effluents arising from mechanical engineering, instrumentation, chemical, petroleum-refining, pulp-and-paper and others industries.

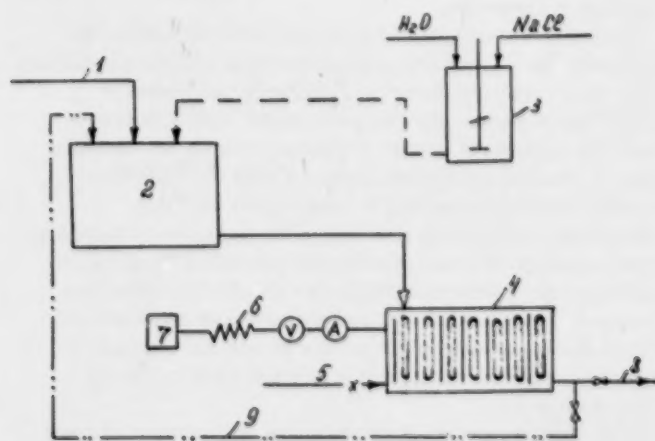
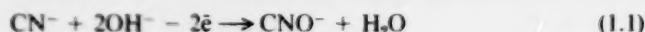


Figure 1.
The Scheme of Principal of the Installation for the Electro-Chemical Purification of Wastewater from Cyanides.

- 1.—feeding of the wastewater;
- 2.—accumulator;
- 3.—tank for the preparation of the NaCl solution;
- 4.—electrolyser;
- 5.—feeding of the air;
- 6.—regulator of the current;
- 7.—the source of the constant current;
- 8.—fault in the sewerage system;
- 9.—return of the water for further treatment.

The removal of pointed out above-compounds from waste effluents is based upon anodic oxidation and cathodic reduction.

The principal flowsheets for removal of cyanide compounds from wastewaters by electrochemical oxidation is given in Fig. 1. The process is carried out in electrolysis units operating without diaphragm. Plates or rods of graphite carbon, which are utilized in the production of chlorine and sodium hydrate by electrochemical method, are used as anodes. The anodes may be of magnetite and ruthenium dioxides (with titanium substrate) as well. Plates of alloy steel serve as cathods. While electrolyzing alkaline waste effluents, containing simple and complex cyanides, the latter are oxidized to cyanates at the anode:



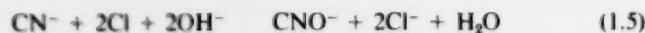
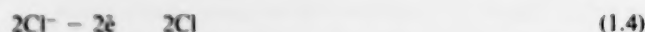
As the concentration of cyanate ions in the solution increases, they are further oxidized at the anode, the final products of which are carbonates and gaseous nitrogen:



The discharge of H^+ ions resulting in the generation of gaseous hydrogen as well as precipitation of metals in the form of cyanide complexes (copper, silver and others) takes place on the cathod.

In order to increase the electroconductivity of wastewaters, the rate of the process and to reduce power consumption, it is advisable to add inorganic salts (predominantly sodium chloride) to wastewaters prior to the electrolysis and to adjust the pH to 9–10 by addition of alkalis.

When sodium chloride is added to waste effluent besides electrochemical oxidation, cyanides are oxidized by metallic chlorine, being generated at the anode as a result of electrochemical decomposition of NaCl.



The process is carried out at the anode current density of 20–100 A/m² with addition of 3–4 kg/m³ of soda and sodium chloride (volume density is 1–3 A/l). Power consumption required for treating wastewaters containing cyanides at a concentration of 30–200 mg/l varies between 4 to 40 kWh/m³ (about 0.2 kilowatt-hour per gram of cyanide ions). 100% treatment efficiency is achieved. 80% of total amount of non-ferrous metals present in wastewaters recovered as cathodic deposits are utilized.

Cathodic reduction of organic compounds from wastewaters is desirable if direct anode oxidation doesn't occur or requires high power consumption, and products formed during cathodic oxidation are either non-toxic or subjected to oxidation with destruction.

During the electrolysis of wastewaters containing heavy metal ions, the ions are discharged at the cathod, thus producing deposits of corresponding metals (copper, zinc and others). Organic nitro-compounds (nitro-benzene, trinitro-toluene and others) are removed from wastes in an electrolysis cell with porous inert diaphragms made of synthetic materials (Mipor, polyethylene, Miplast). Plates of lead, zinc, copper, alloy steel are employed as cathods. Wastewater is introduced into the cathod compartment.

After reduction of nitro-compounds, wastewaters are subjected to secondary electrochemical treatment, that is, amines formed are oxidized to non-toxic products at the anode. Waste effluents, containing trinitro-toluene are treated by electrochemical process employing steel cathods and graphite anodes at current densities of 200–600 A/m² and at temperature of 30–50° C.

Power consumption required for removal of gram of trinitro-toluene from wastewaters is 0,5 kwh. In some cases, cathodic reduction of organic substances results in the formation of water-insoluble precipitates.

Thus, for example, while treating-wastewaters from anthraquinone sulfonic acid manufacturing process (semi-product of the synthesis of anthraquinone dyes) by electrochemical process using mercury cathod, reaction of desulfation (reduction) of anthraquinone sulfonic acid to anthraquinone which precipitates, takes place. The product may be utilized in the process.

Electrodialysis

Electrodialysis - is a process of separating salt ions which is carried out in multi-cell electrodialysis unit operating with ion-exchange membranes by the action of direct current, directed perpendicularly to the surface of membranes.

At present, electrodialysis is widely used for desalination of salty underground and sea waters. The principles of operation of electrodialysis units are well known and details are not discussed in this paper.

In recent years, this method has been finding increased use in the treatment of wastewaters for removal of salts (mine waste effluents) and, especially, in regeneration of valuable components from various spent process solutions and electrolytes. Relatively high specific consumption of power required for treatment of strong wastewaters, in many cases, is compensated by the cost of regenerated products (acids, alkalies etc). The method may be applied at low flow rates of concentrated wastes.

Methods of regeneration of some electrolytes using electrodialysis process have been developed by Institute VODGEO.

While electrolyzing spent chromic acid solutions in the anode compartment employing electrochemically active cation-exchange membranes, cations of iron, trivalent chrome, copper, which contaminate given electrolyte, are removed from anode liquor.

The regenerated chromic acid solution is reused in the process, metal cathodic deposit, may be utilized.

Power required for regeneration of one cu.m. of spent solution varies between 800–2000 kilowatt-hours depending on

the concentration of other impurities. The method is expedient due to high cost of the products being regenerated (chromic acids, copper as a metal).

Electrodialysis employing ion-exchange membranes allows to regenerate inorganic acids and to recover metals from spent pickling solutions. Thereby, 80–90% of acids used in pickling processes may be regenerated and reused.

Power consumption required to treat one cu.m. of spent pickling solutions is 1000–1200 kilowatt-hours.

Electrochemical regeneration of spent solutions, originating from pickling products of copper and its alloys in sulfuric acids, is carried out employing lead anodes and copper cathods at current densities of 2 A/dm². Thereby the consumption of sulfuric acid is reduced by a factor of two or three during the pickling process, and the volume of spent solutions to be discharged is reduced by a factor of five-six.

Electrolysis of wastewaters using soluble anodes.

The main advantages of so called electrocoagulation method over coagulation with addition of chemicals are: the apparatus (electrolysis cell) employed for detoxification is more compact and its operation is simple; detention periods are shortened; feeding equipment is reduced or absent; solid phase in sludge produced is reduced.

Due to electrolytic dissolution of anodes of steel or aluminium the latter in the neutral or weakly alkaline media form hydroxides.

As a result, coagulation process takes place and is analogous to the treatment with adequate salts of iron and aluminium. However, during electrocoagulation, liquid is not enriched with anions and salt content doesn't increase, which is of importance, if treated effluent is recycled in industrial water supply, in comparison with conventional treatment with addition of chemicals.

During electrocoagulation treatment of wastewaters, the following electrochemical, physicochemical, chemical processes take place: 1) electrophoresis, 2) cathodic and chemical reduction of organic and inorganic matter and formation of cathodic deposits of metals; 3) chemical interaction between ions of iron and aluminium, formed during the dissolution of anodes, and anions present in wastewaters (sulfides, phosphates and others), resulting in the formation of insoluble compounds; 4) flotation of solid and emulsified impurities by hydrogen gas bubbles produced on cathod (electroflotation process); 5) sorption of ions and molecules of dissolved and emulsified impurities on the surface of iron and aluminium hydroxides having considerable sorption capacity during formation process.

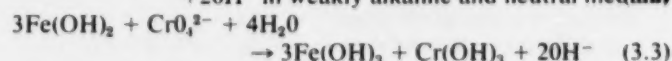
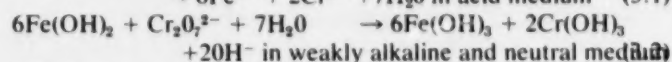
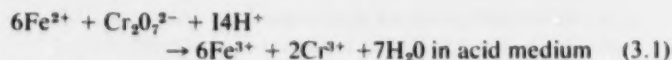
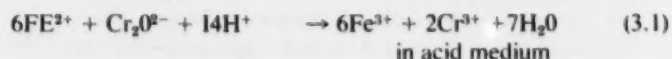
The methods applied in combination, in a number of cases, provide relatively high removal efficiency of dispersed as well as some dissolved impurities. The efficiency appears to be higher than that achieved while treating wastewaters with the same doses of salt coagulants (estimated on the metal used).

Electrolytic coagulation in conjunction with electroflotation (or alone) is, mainly, employed for removal of dispersed impurities, which form stable colloidal systems in liquid, from wastewaters. The process has limited application in removal of dissolved impurities. Generally, these impurities form insoluble

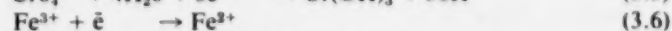
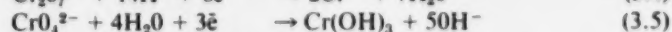
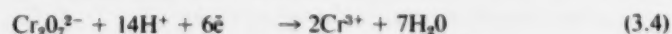
compounds (sulfide-, phosphate-, fluoride-ions) with ions of iron and aluminium.

The steel anodes are effective in the removal of chromate-ions, which are present in wastewaters, discharged from various industries.

The removal of hexavalent chrome compounds from wastewaters is based upon the chemical reduction of bichromate- and chromate-ions by divalent iron ions, formed during electrolytic dissolution of anodes as well as hydroprotoxide of iron according to the following equations:



Electrolysis, under these conditions, may result in partial reduction of chromate- and bichromate -ions resulting from cathodic electrochemical processes.



During the electrolysis the increase in the pH and formation of hydroxides of metals, ions of which are present in wastewaters, take place. As a result, simultaneously with chrome compounds are removed ions of other heavy metals, which is rather considerable (in some cases removal efficiency is high). The principle flow sheet for treating chrome containing wastewaters is given in Fig. 2.

It is advisable to apply the process at hexavalent chrome concentration up to 100 mg/l. At higher concentrations consumption of metal increases, rapid passivation of surfaces of steel anodes occur; power consumption increases considerably.

At optimum pH value of 3-5 and concentration of Cr^{6+} of 50-100 mg/l, consumption of metallic iron is 2 parts per 1 part of Cr^{6+} by weight, which is lower than theoretical value calculated according equations (3.1), (3.2), (3.3).

In practice power consumption required for complete reduction of hexavalent chrome appears to be close to the theoretical value.

The consumption of sheets during electrocoagulation limits its wide implementation. In practice only less than 80% of metals of electrodes is utilized.

These disadvantages may be eliminated by modification of apparatus used for electrocoagulation and wastewater treatment schemes. □

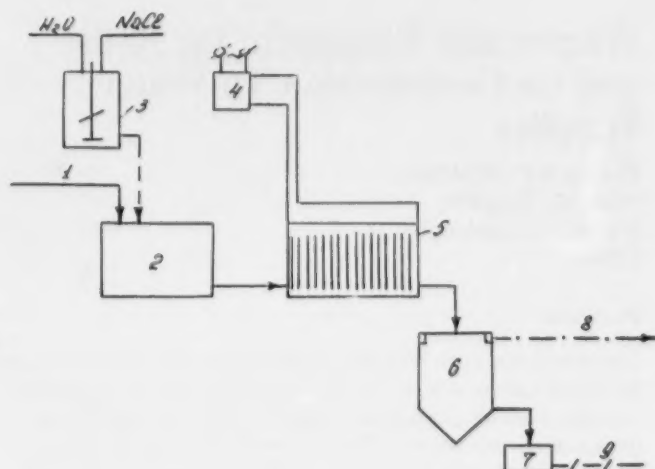


Figure 2.
The Scheme of the Principal of the Treatment of Wastewater, Containing Chromium, by Means of the Electrocoagulation.

- 1.—feeding of the wastewater;
- 2.—accumulator;
- 3.—tank for the preparation of the NaCl solution;
- 4.—the source of the constant current;
- 5.—electrolyser;
- 6.—settler;
- 7.—installation for the dehydration of sludge;
- 8.—treated water;
- 9.—sludge for the fault.

Wastewater Treatment for Reuse and Its Contribution To Water Supplies

Howard P. Warner,
John N. English,
Irwin J. Kugelman,
EPA

Disclaimer

This report has been reviewed by the Municipal Environmental Research Laboratory, U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Foreword

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the projects of that research; a most vital communications link between the researcher and the user community.

The study summarized in this report evaluates a combined biological/physical-chemical pilot treatment system designed to produce a high quality reusable water. Process reliability is established and effluent constituents are related to similar materials identified in finished drinking waters.

Francis T. Mayo

Director

Municipal Environmental Research Laboratory

Abstract

An 18 month study using cost effective municipal wastewater treatment technology coupled with a computerized data handling system, was conducted at the EPA/Washington, D.C. Blue Plains Pilot Plant to obtain data on the safety of the effluent for discharge upstream of drinking water intakes, and for potential domestic reuse purposes. Treatment reliability was demonstrated and performance results showed the absence of virus in the effluent. Effluent concentrations of radioactivity, trihalomethanes and other volatile organics, heavy metals, pesticides, TOC, turbidity, general inorganic compounds, and pathogenic indicator organisms were shown to be similar to those found in finished drinking waters during the EPA National Organics Reconnaissance Survey in 1975. The specific organic compounds identified in the effluent are also present in finished drinking waters. Effluent organic concentrates did not exhibit mutagenic properties, and results of an 80 element survey did not detect the presence of significant quantities of any hazardous inorganic material. Effluent endotoxin levels were comparable to levels in public drinking water supplies.

This report was submitted in partial fulfillment of contract No. 68-03-0344 by the District of Columbia Pilot Plant under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from April 1975 to September 1976.

Acknowledgments

A project of this magnitude, which covers 18 months of pilot plant operations, could not have been accomplished without the assistance of the entire EPA-DC Pilot Plant staff.

Mr. Paul Ragsdale supervised the mechanics and instrumentation personnel. Mr. Calvin Taylor served as chief operator. Laboratory analyses were performed under the direction of Mr. David Rubis. The efforts of all the D.C. mechanics, technicians, crew chiefs, operators and laboratory personnel are gratefully acknowledged.

Mr. Thomas A. Pressley and Ms. Stephanie G. Roan, On-site EPA staff, performed the detailed organic identification work and virus analyses were conducted by the Cincinnati EPA Virology Laboratory under the direction of Mr. Daniel R. Dahling.

Special thanks are due Mr. Thomas P. O'Farrell, past Pilot Plant Chief, for his efforts in the early stages of the project which enabled a timely completion of fabrication of the treatment system.

Introduction

We are living in a Nation where millions of people are presently reusing wastewater indirectly for domestic purposes. Severe contamination of many surface supplies has occurred, as evidenced by the identification of carcinogenic organic materials in finished drinking waters, and increasing instances of groundwater contamination are being found. There is a concern on the part of health agencies in areas that use surface supplies for domestic purposes as to the potential hazards of the present covert reuse of wastewater discharged upstream of

drinking water intakes. Since the typical wastewater treatment plant does not remove all of the contaminants from the wastewater there is a basis for this concern, and thus a need to know the appropriate levels of municipal treatment to ensure the safety of water supply intakes in the vicinity of the discharges.

The concerns of health agencies where covert reuse is prevalent are also receiving attention by health agencies in the more arid areas of the U.S. where water utilities are proposing the overt domestic reuse of wastewater to supplement depleted groundwater supplies and unreliable surface sources. Concerns about both covert and overt reuse are the same since the problems and the research data required to solve the problems are the same. The questions that need answers are:

- What are the health effects of the covert/overt reuse of wastewater?
- What technology is needed to remove potential hazardous materials?

The Environmental Protection Agency (EPA) through its Municipal Environmental Research Laboratory (MERL) in Cincinnati, Ohio is addressing the technology question by characterizing the ability of municipal wastewater treatment systems to remove pollutants of health concern and providing knowledge of treatment system performance variability and reliability.

A combined biological/physical-chemical treatment system designed to produce a high quality reusable water has been in operation at MERL's Washington, D.C. Pilot Plant for 18 months as part of a project that had the following objectives:

- Identification of specific pollutants in the final effluent and evaluation of the performance of the individual processes in removing these pollutants.
- Provide data on process and system performance variability and reliability with respect to pollutant removals.

Conclusions

Performance results showed the absence of virus in the effluent, and concentrations of radioactivity, trihalomethanes and other volatile organics, heavy metals, pesticides, TOC, turbidity, and microbiological parameters similar to those found in finished drinking waters during the EPA National Organics Reconnaissance Survey in 1975. The specific organic compounds identified in the effluent are also present in finished drinking waters. Effluent organic concentrates did not exhibit mutagenic properties and results of an 80 element survey did not detect the presence of significant quantities of any hazardous inorganic material. Effluent endotoxin levels were comparable to levels in public drinking water supplies.

Treatment reliability was demonstrated as evidenced by the frequency distribution of the day to day concentrations of chemical, physical, and biological materials remaining in the effluent. In full scale facilities employing similar treatment processes and located upstream of drinking water intakes, or designed for domestic reuse purposes, reliability can be further enhanced by in-plant storage facilities to provide flexibility, process control instrumentation, and dedicated operating

personnel. In planned reuse situations where a monetary value is set on the water, or where enforced legal restraints are placed on effluent quality reliability will become very good.

Description of Treatment System

The treatment system is located on the grounds of the Washington, D.C. Blue Plains wastewater treatment facility and is supervised by MERL staff and operated in cooperation with the Washington, D.C. Department of Environmental Services. The system treats degrittied D.C. municipal wastewater using a screening device to remove coarse materials, lime clarification, dispersed growth nitrification, fixed film denitrification, carbon adsorption, dual media filtration, and chlorination for disinfection. This sequence of processes was chosen because of past experience with the performance of the individual processes and compatibility of the unit processes when combined into a treatment system that could produce a reusable high quality water from municipal wastewater. Also, a similar treatment system was identified at a workshop on "Research Needs for the Potable Reuse of Municipal Wastewater" ⁽¹⁾ as one of four treatment systems that had potential as a cost-effective treatment for potable reuse.

A schematic flow diagram of the treatment system is presented in Figure 1 and the design and operating conditions are summarized in Table 1. The system operates continuously at 35 gpm (2.2 l/s). The backwash water from the denitrification, carbon adsorption, and filtration processes are returned to the influent of the lime clarification processes. A portion of the sludges from the lime clarification and nitrification processes are wasted to maintain process equilibrium.

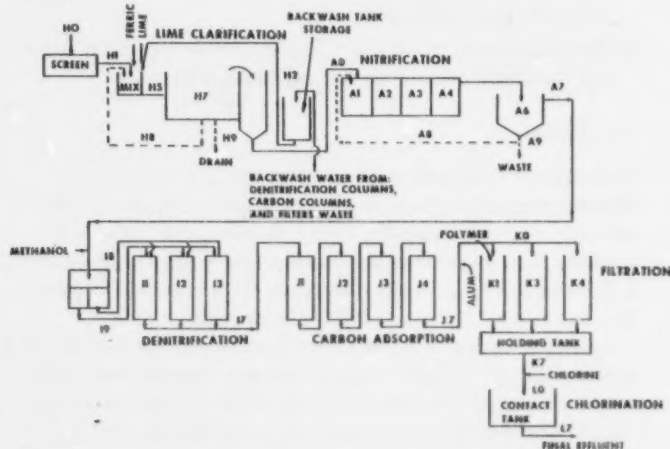


Figure 1.
Schematic Flow Diagram

The treatment system was operated on a continuous basis with operators assigned to three, 8 hour shifts each day. Samples were taken manually by the operators and composited in refrigerated containers as required. Twenty-four hour composites were taken 5 days per week and no sampling was done between Friday 8 a.m. and Sunday 8 a.m. Other types of

Table 1
Design Data and Operating Conditions

Parameter	Value
Raw Wastewater (Constant Flow)	35 gpm ($2.2 \times 10^{-3} \text{ m}^3/\text{s}$)
Screening Device	
Type	Bauer Hydrasive Model 552
Size of Openings	0.040 in. (1.02 mm)
Lime Clarification	
Lime Dosage (pH 10.0) (as CaO)	200 mg/l
FeCl ₃ Dosage (as Fe)	15 mg/l
Hydraulic Loading Rate	1050 gpd/sq. ft. ($42.8 \text{ m}^3/\text{m}^2\text{d}$)
Detention Time	2.7 hr.
Sludge Wasting Rate	2% to 3%
Percent Solids in Waste Sludge	1.5% to 2.0%
Nitrification (Suspended Growth)	
Detention Time	3.5 hr.
MLSS	200 mg/l
SRT	8 day
Air Requirement	1450 cu. ft./lb BOD ($90.6 \text{ m}^3/\text{kg}$)
Clarifier Overflow Rate and Detention Time	526 gpd/sq. ft. ($21.4 \text{ m}^3/\text{m}^2\text{d}$) 2-3.6 hr.
Denitrification (Fixed Film)	
Media Size	3 to 6 mm
Specific Surface Area	245 sq. ft./cu. ft. ($900 \text{ m}^2/\text{m}^3$)
Hydraulic Loading Rate	5.9 gpm/sq. ft. ($4.1 \text{ l/m}^2\text{s}$)
Methanol/NO ₃ -N Ratio	2:1 to 4:1
Bed Depth	15 ft. (4.6 m)
Detention Time (Empty Bed) Operation	9.5 min. Downflow Packed Bed
Granular Carbon Adsorption	
Detention Time (Empty Bed)	35 min.
Hydraulic Loading Rate	7 gpm/sq. ft. ($4.8 \text{ l/m}^2\text{s}$)
Columns in Series	4
Carbon Size (Filtrisorb 300) Operation	8 x 30 Mesh Downflow Packed Bed
Filtration with Alum and Polymer	
Hydraulic Loading Rate	3 gpm/sq. ft. ($2.04 \text{ l/m}^2\text{s}$)
Dual Media	
Coal 1.2-1.4 mm	2.0 ft. (0.61 m)
Sand 0.6-0.7 mm	1.0 ft. (0.30 m)
Alum	5 mg/l
Disinfection with Chlorine	
Detention Time	20 min.
Residual	1 mg/l Free Available

sampling were also done manually by the operators as required.

Establishing the reliability of any treatment system requires a long-term program of routine monitoring of the system performance. A mass of valuable data was obtained as a result of this program and an efficient computerized data storage and retrieval system was developed to sort large quantities of data per month from 37 performance or process monitoring stations. The data storage and retrieval system was designed for use on the EPA UNIVAC 1110 Computer located at EPA Research Triangle Park in North Carolina. All the programs run in batch or demand mode. The system is modular in design to allow the addition and modification of programs without affecting the system integrity. Data is entered into and withdrawn from the computer using a terminal hookup. Statistical reports, data listing, as well as data plots can be obtained as required by project personnel to aid in establishing the system performance credibility.

Performance

Virus

Virus in wastewater effluents are of concern to health agencies dealing with the use of contaminated surface drinking water supplies and proposed domestic reuse situations. For this reason it is important that virus analyses be included in any

reuse technology monitoring program. Virus and other pathogens were monitored at various points in the treatment system on three occasions over a three month period using methods described by Rao, V.C., et al ⁽¹²⁾ and Wallace, C., et al ⁽¹³⁾.

Samples of the raw sewage, finished effluent, and dual media filtration effluent were taken during the first sampling period. As shown in Table 2 animal viruses in raw sewage samples ranged from about 7000 to more than 17,000 PFU/100 gal (1,850–4,500 PFU/100 l). No animal viruses were observed in the dual media filtration effluent before chlorination, or the finished effluent following concentration of 100–150 gal (379–568 l) of each effluent.

Table 2.
Virus

Sampling Period	Influent	Animal Virus pfu/100 liters		
		PROCESS		
		Nitrification	Filtration	Chlorination
1	1,850-4,500	—	N.D.	N.D.
2	4,500-18,000	N.D.	—	N.D.
3	7,400-18,000	N.D.	—	N.D.

Sample Volumes—189 liters to 900 liters.
N.D.—None Detected.

During the second and third months samples of the raw sewage, finished effluent and effluent from the nitrifying activated sludge were taken. Animal viruses in the raw sewage from 17,000 to 68,000 PFU/100 gal (4,500–18,000 PFU/100 l) and from 28,000 to 68,000 PFU/100 gal (7,400–18,000 PFU/100 l). Animal viruses were not detected in the final effluent in either sampling period. A total of 7 samples were concentrated during these periods ranging in volume from 50 to 238 gal (190–900 l). During the last two sampling periods, effluent from the nitrifying sludge system was tested on five occasions following concentration of 40 to 160 gal (151–605 l) of each system. In this phase of treatment, animal viruses still could not be detected. Assays were carried out on solids remaining on prefilters used for clarifying both the nitrification and final effluents. Viable animal viruses could not be detected after processing these solids.

Radioactivity

Samples of effluent were periodically taken for gross beta and gross alpha analyses and the results are summarized in Table 3. These levels are well below the maximum contaminant level set forth in the EPA Interim Primary Drinking Water Regulations ⁽¹⁴⁾ for radioactivity and they are comparable to those reported in finished drinking water supplies ⁽¹⁵⁾.

Table 4.
Volatile Organics

COMPOUNDS (All Units µg/l)	NUMBER OF SAMPLES	INFLUENT		NUMBER OF SAMPLES	EFFLUENT		* FINISHED DRINKING WATERS RANGE OF CONCENTRATION NS	DRINKING WATER WASHINGTON, D.C. (DEACARLIA PLANT)
		ARITH. MEAN	RANGE		ARITH. MEAN	RANGE		
Chloroform	14	13	4.44	12	8.0	< 0.1-22	< 0.1-311	41
Bromodichloromethane	14	0.9	< 0.1-4.5	12	5.4	< 0.1-21	0.3-116	8
Dibromochloromethane	14	5.9	< 0.1-23	12	5.2	< 0.1-28	< 0.4-110	2
Bromoform	14	< 0.1	< 0.1-0.2	12	2.6	< 0.1-23	< 0.8-92	**N.D.
Carbon Tetrachloride	13	5.6	< 0.1-32	11	1.0	< 0.1-5.2	< 2-3	N.D.
1,2-Dichloroethane	14	9.7	< 0.1-134	12	0.5	< 0.1-2.6	< 0.2-6	< 0.3

* Based on 80 samples from National Organics Reconnaissance Survey—“Preliminary Assessment of Suspected Carcinogens in Drinking Water, Report to Congress”, EPA, December 1975.

** N.D.—None Detected.

Volatile Organics

Four trihalomethanes, carbon tetrachloride, and 1, 2 - dichloroethane were determined in the influent and effluent from individual processes on a twice per month basis to determine the effectiveness of the treatment system in removing these materials. A summary of the influent and effluent concentrations of the compounds compared to the range of concentrations found in finished drinking water supplies is included in Table 4. Figure 2 shows the variation of the volatile organics through each process. Although the concentrations are quite low there is definite indication that chlorination increases the quantities of each of the six compounds.

Table 3.
Radioactivity

Sampling Period	Effluent Values pci/l	
	Gross Alpha	Gross Beta
1	< 0.3	7.9 ± 0.9
2	< 0.5	8.1 ± 0.9
3	< 0.5	7.4 ± 0.9
4	< 0.5	5.0 ± 0.9

Average in Drinking

Water* 5.5 2.9

* Summary of Interstate Carrier Water Supply Radionuclide Data “Preliminary Assessment of Suspected Carcinogens in Drinking Water” EPA, December 1975.

Table 5 shows the results of analyses of other volatile organics in the pilot plant influent and in the effluent from various unit processes. The types of compounds and their corresponding concentrations are similar to those present in finished drinking water supplies ⁽¹⁵⁾. Blanks in the tables indicate the compounds were below the detection limit of the GC/MS technique used ⁽¹⁶⁾.

Toxicity Screening

Organic materials were concentrated from 500 gal (1,900 l) samples of effluent using a reverse osmosis technique that employed cellulose acetate and nylon membranes in series ⁽¹⁷⁾. The concentrate from each type membrane was extracted with pentane or methylene chloride at acidic (pH 2) and neutral (pH 7) conditions. The separate extracts and a composite of the extracts were tested for mutagenicity using the Ames procedure ⁽¹⁸⁾ that utilizes *in vitro* microbiological assays with strains of *Salmonella Typhimurium* TA 98 and TA 100. No mutagenicity was detected as shown by the data in Table 6.

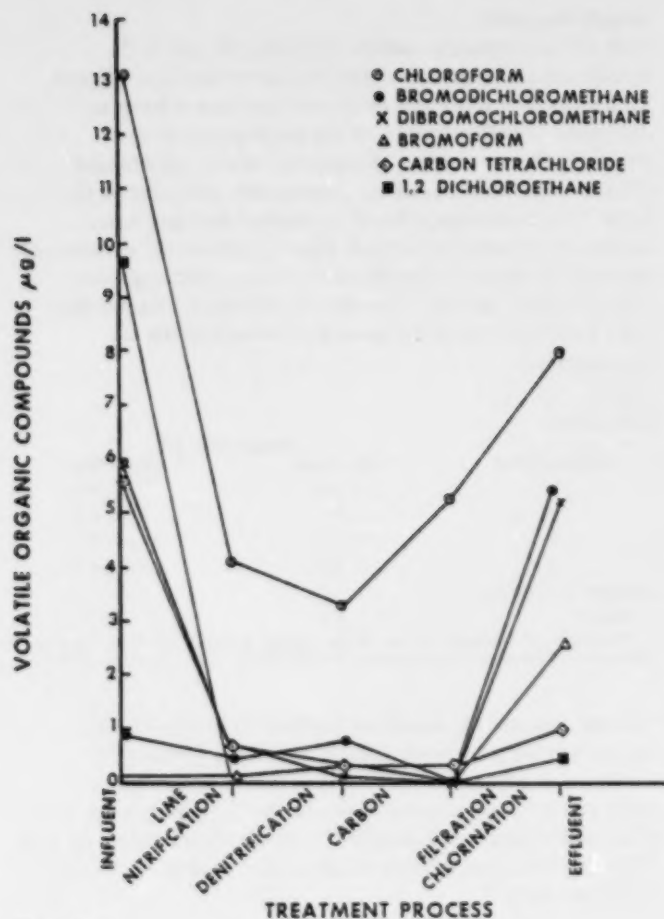


Figure 2.
Removal of Volatile Organics.

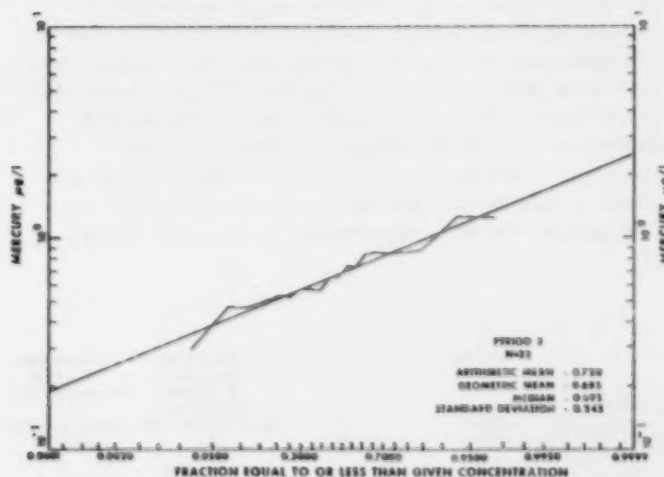


Figure 3.
Frequency Distribution of Effluent Mercury.

Table 5.
Volatile Organics in Process Effluents

Compound (Unit µg/l)	Influent	Nitri- fication	Denitri- fication	Carbon	Chlorina- tion	Drinking Water**
Acetaldehyde	TR.*		TR.	TR.		✓
Methanol	TR.					✓
Acetone	TR.	TR.	TR.	TR.	TR.	✓
Dichloromethane	4		TR.	1	TR.	✓
Acrolein	TR.		TR.		TR.	
Carbon Disulfide	TR.			TR.	TR.	✓
Chloroform	10	3	2	5	7	✓
Bromodichloro- methane	1	TR.			4	✓
,1,1-Tri- chloroethane	TR.					✓
Chlorodi- bromoethane	4	TR.		TR.	2	✓
Benzene	2	1	1	1	2	✓
Dimethyl disul- fide	3					✓
Toluene	2	TR.	TR.	TR.	TR.	✓
N-Hexanol			TR.	TR.		
Tetrachloro- ethylene	3					✓
Xylene	TR.		TR.	TR.	TR.	✓
Alkyl benzene	TR.	TR.				
Benzaldehyde			TR.		2	✓
Carbon tetrachloride	2	TR.		TR.	Tr.	✓

* TR. — Trace (< 1 µg/l).

** "Preliminary Assessment of Suspected Carcinogens in Drinking Water." Report to Congress, EPA, Dec. 1975.

Table 6
Mutagenicity of Organic Concentrates

R.O. Membrane and Solvent Fraction	*Mutagenic Potential
Cellulose Acetate	
• Pentane	**N.D.
• Methylene Chloride Neutral	N.D.
• Methylene Chloride Acidic	N.D.
Nylon	
• Pentane	N.D.
• Methylene Chloride Neutral	N.D.
• Methylene Chloride Acidic	N.D.
Composite	N.D.

* *In Vitro* with strains of salmonella typhimurium TA98 and TA100.

** N.D. — None Detected.

Table 7
Results of Bacterial Endotoxin Testing*

SOURCE	ENDOTOXIN EQUIVALENTS ng/ml
Blue Plains Reuse System	2.5-12.5
Public Drinking Water Systems	
1	1.25
2	12.5
3	2.5
4	12.5
5	0.625
6	500.0
7	125.0
8	10.0
9	2.5
10	

* Limulus Assay Procedure—Jorgensen et al., Applied and Environmental Microbiology, September 1976.

Table 8
Heavy Metals

Metal (Unit- μ g/l)	n	Final Effluent		Washington, DC Drinking Water*	EPA Regulations**
		Arit. Mean	Range		
Mercury	47	0.666	0.100-1.25	< 0.5	2
Cadmium	44	0.143	0.020-0.530	< 2	10
Selenium	38	4.76	2.00-5.00	< 5	10
Chromium	57	2.24	0.600-4.30	< 5	50
Lead	53	0.308	0.030-1.07	< 5	50
Manganese	60	7.96	1.40-20.0		
Arsenic	56	2.25	0.300-6.00	< 5	50
Iron (mg/l)	227	0.0599	N.D.-0.810		
Barium	49	82.3	3.10-200	< 50	1000
Copper	56	4.86	1.40-21.0		
Zinc	57	10.6	5.10-19.1		
Boron (mg/l)	8	0.313	0.300-0.400		
Fluoride (mg/l)	62	0.722	0.380-1.10	1.0	1.8 @ 64°F
Silver	49	0.134	0.009-0.400	< 10	50
Cyanide	32	4.23	1.00-9.80	< 20	
Aluminum (mg/l)	210	0.251	N.D.-0.900		

* Preliminary Assessment of Suspected Carcinogens in Drinking Water. Report to Congress, EPA, December 1975.

** National Interim Primary Drinking Water Regulations, EPA, Federal Register, Vol. 40, No. 248, December 1975.

Table 7 shows the results of bacterial endotoxin tests on effluent samples as compared to similar data from ten public drinking water systems. These results were reported by Jorgensen, J.H., et al.⁽⁹⁾ from studies in which they used a Limulus assay technique for the detection of bacterial endotoxins. The concentration of endotoxins in the Blue Plains effluent is comparable to the concentrations in public drinking waters.

Metals

Data on the metals present in the influent and effluent are presented in Table 8 along with a list of the concentrations present in the Washington, D.C. drinking water, and the levels allowed in finished drinking water supplies as contained in the "EPA National Interim Primary Drinking Water Regulations", December 1975⁽¹⁰⁾. None of the effluent samples taken exceeded metal concentrations cited in the EPA regulations. The reliability of the treatment system to meet these regulations is further demonstrated by the frequency distribution of effluent mercury for the second four month period of operation as shown in Figure 3. All twenty two of the data values were less than the 2 μ g/l standard. The median value was 0.70 μ g/l.

In addition to determining metals in samples of the AWT system influent and effluent, the effluent from the lime clarification process was monitored for a four month period since previous data has shown that heavy metals can be removed by this process. Table 9 shows that concentration of metals in the influent, after the lime process, and in the final effluent. It is evident that the lime process is primarily responsible for the reduction in the metal concentrations.

Pesticides

Pesticide analyses were made on a less frequent basis than were analyses for metals. The data presented in Table 10 are based on samples taken twice per month. The levels in the effluent are significantly less than the EPA standards for drinking water that are listed in the table.

Table 9
Heavy Metal Removal by Lime Clarification

Metal (Unit- μ g/l)	Influent	Lime Clarification	Final Effluent
Mercury	0.813	0.931	0.802
Cadmium	1.92	—	0.143
Selenium	4.76	—	4.76
Chromium	16.9	5.59	3.18
Lead	23.4	0.862	0.399
Manganese	149	19.5	5.04
Arsenic	1.49	1.05	0.967
Iron (mg/l)	1.30	—	0.0467
Barium	54.3	34.3	27.2
Copper	48.9	7.72	5.66
Zinc	110	10.7	12.6
Boron (mg/l)	0.250	—	0.313
Fluoride (mg/l)	0.701	0.679	0.724
Silver	3.98	0.333	0.0987
Cyanide	5.80	—	4.23
Aluminum (mg/l)	—	—	0.251

Table 10
Pesticides

Pesticide Unit- μ g/l (ppt)	Effluent**	*EPA Regulations
Aldrin	4	
DDT	10	
Dieldrin	1	
Endrin	5	200
Heptachlor	0.7	
Heptachlor Epoxide	1	
Lindane	2	4000
Methoxychlor	40	10 ⁵
Diazin	5	
Guthion	200	
Malathion	10	
Parathion	10	

* EPA National Interim Primary Drinking Water Regulations, Federal Register, Vol. 40, No. 248, December 24, 1975.

** Average of 4 data values for each pesticide.

Table 11
General Organics
PARAMETER

(units—mg/l)	N*	INFLUENT		N	EFFLUENT	
		Arithmetic Mean	Standard Deviation		Arithmetic Mean	Standard Deviation
TOC	231	74.1	11.0	234	2.79	1.35
COD	229	240	30.5	226	6.53	3.12
BOD	245	106	15.7	221	3.12	2.15
MBAS	13	8.92	1.71	35	0.14	0.08
CCE	—	—	—	2	0.75	0.64
CAE	—	—	—	2	2.25	0.64
Phenol (μg/l)	9	12.9	4.02	54	3.66	1.52
UV @ 290 mμ (%T)	—	—	—	19	96.9	0.87

* N—number of samples.

General Organics

A summary of various gross measurements or organics in the influent and effluent is presented in Table 11 and includes the average of the parameters for a 14 month operation period. The treatment system is capable of reliably producing a high quality effluent on a continuous basis as evidenced by the TOC data presented in Table 12 and Figure 4. The 311 pieces of TOC data were grouped into 5 periods covering 18 months of operation and the arithmetic averages and standard deviations were determined. The average TOC in the finished drinking waters from 80 U.S. cities⁽⁵⁾ is included in Table 12 for comparison purposes.

Table 12
Variability of Effluent TOC

4 Month Periods	Number of Samples	Arithmetic Mean (mg/l)	Standard Deviation
1	58	2.26	1.31
2	64	2.35	1.00
3	69	3.72	1.59
4	43	2.67	1.50
5	77	2.68	1.02
Total	311	2.76	—
* Finished Drinking Water	80	2.21	Range 0.05-12.2

* "Preliminary Assessment of Suspected Carcinogens in Drinking Water." Report to Congress, EPA, December 1975.

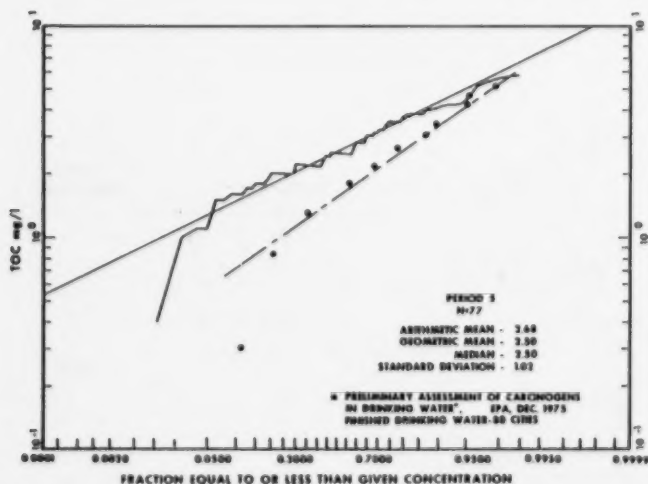


Figure 4.
Frequency Distribution of Effluent TOC.

Figure 4 is a frequency distribution of 77 pieces of TOC data taken during the fifth and last period of operation. Included in the figure for comparison purposes is a frequency distribution of the TOC data from 80 drinking waters taken during the National Organics Reconnaissance Survey in 1975⁽⁵⁾. The median TOC concentrations were 1.5 mg/l for the drinking waters and 2.5 mg/l for the wastewater effluent. The lower levels of TOC in the drinking water data may be attributed to the cities in the survey using groundwater supplies.

In an attempt to determine if additional TOC reduction was possible grab samples of effluent were ozonated on three separate occasions. An ozone dosage of 60 mg/l in the gas stream was introduced into a 1 liter sample using the reactor system described by Roan, S.⁽¹⁰⁾. The sample was reacted with the ozone stream for 60 minutes. The initial average TOC concentration was 1.21 mg/l and the final TOC was 0.84 mg/l which is a reduction of 30 percent. In addition, a short term side stream study was conducted using a strong acid cation resin in series with an intermediate base anion resin to determine the removal of the remaining TOC by ion exchange. These resins reduced the effluent TOC about 40 percent.

Figure 5 shows a graph of the removal of TOC by each of the processes in the treatment system. Ninety-two percent of the TOC is removed in the lime clarification and nitrification processes. The increase in TOC in the denitrification process effluent is due to some leakage of methanol.

Table 13 shows the variability of the effluent COD for each of the five operating periods and Figure 6 shows a frequency distribution of 74 pieces COD data taken during the fifth operating period. The median COD value is 5.61.

Table 13
Variability of Effluent COD

4 Month Periods	Number of Samples	Arithmetic Mean (mg/l)	Standard Deviation
1	58	5.28	2.55
2	64	5.96	3.09
3	67	7.64	2.54
4	37	7.45	3.29
5	74	6.25	2.20
Total	300	6.45	—

Table 14
General Inorganics
PARAMETER

(unit—mg/l)	N*	INFLUENT Arithmetic Mean	Standard Deviation	N	EFFLUENT Arithmetic Mean	Standard Deviation
pH	2274	7.20	0.118	1081	7.34	0.146
Total Alkalinity	2435	125	15.1	980	102	12.1
Conductivity (μ mhos/cm)	—	—	—	830	514	36.0
TDS	137	283	28.6	210	357	31.6
Hardness	35	115	7.65	40	162	7.18
CaCO ₃ Stability	—	—	—	40	0.198	0.394
Chloride	—	—	—	158	68.6	4.56
Sulphate	—	—	—	122	50.1	3.83
Calcium	176	31.2	2.73	218	56.6	4.40
Magnesium	178	6.47	0.579	224	5.49	0.481
Sodium	—	—	—	228	34.1	2.94
Potassium	—	—	—	21	8.23	0.318

* N—number of samples.

General Inorganics

A summary of the inorganic constituents in the influent and effluent is presented in Table 14. The arithmetic means and standard deviations of each constituent are shown. Samples of the effluent were checked for 80 elements by the Proton Induced X-ray Emission Procedure⁽¹¹⁾ to determine the presence of any unusual inorganic component. The results are shown in Table 15. No significant concentrations of hazardous inorganics were observed.

Table 15
Results of 80 Element Survey*

Elements Detected in Effluent (mg/l)		
Na—37.8	Zn—0.017	Ba—0.034
K—7.08	Cd—0.002	As—0.006
Ca—54.0	I—0.013	Ni—0.004
V—0.003	Pb—0.003	Cu—0.013
Cr—0.001	Ga—0.001	Sr—0.151
Fe—0.031	Br—0.100	Sn—0.002
Co—TR.	Rb—0.007	S—2.85
Elements Not Detected (mg/l)		

Mn, Mo, Ag, Sc, Ti, Ge, Y, Pd, In, Sb, Te, Cs, La, W, Pt, Tl, Bi, Si, P,
Ar, Se, Kr, Zr, Nb, Ru, Rh, Xe, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho,
Er, Tm, Yb, Lu, Hf, Ta, Re, Os, Ir, Au, Hg, Po, At, Rn, Fr, Ra, Ac, Th.

Pa, U, Np, Pu

* Proton—induced X-Ray Emission Procedure.

Table 16
Nutrients

PARAMETER (unit— mg/l)	N*	INFLUENT Arithmetic Mean	Standard Deviation	N	EFFLUENT Arithmetic Mean	Standard Deviation
TPO ₄	244	15.1	2.19	232	0.153	0.09
TKN	128	19.0	2.50	98	0.222	0.17
NH ₃ -N	243	17.5	2.32	223	0.069	0.15
NO ₃ +NO ₂ -N	232	0.095	0.08	229	3.84	1.84

* N—number of samples.

** N.D.—none detected.

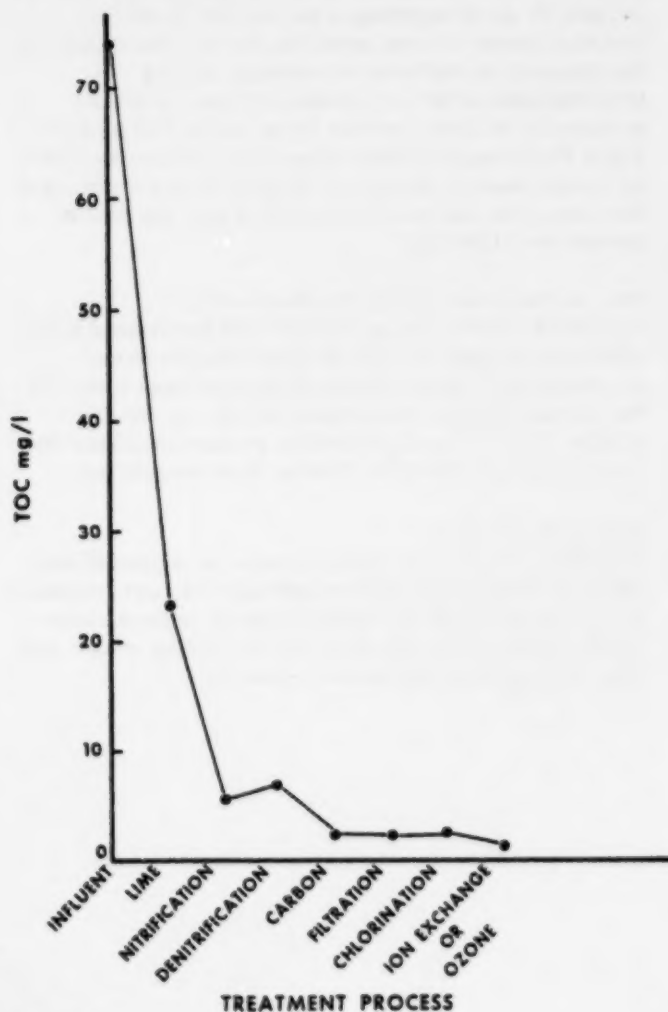


Figure 5.
Removal of TOC.

Nutrients

The concentration of the phosphorus and nitrogen compounds are shown in Table 16. Over 200 pieces of data were used for each parameter in determining the means and standard deviations. No attempt was made to completely denitrify the effluent. The amount of methanol added to the denitrification process was based on allowing 2 to 4 mg/l of NO-N in the effluent.

Suspended Matter

Turbidity, and suspended and total solids data for the treatment system influent and effluent are shown in Table 17. The effluent turbidity level is within the requirements of the EPA National Interim Primary Drinking Water Regulations⁽⁴⁾ which establishes the standard at 1 turbidity unit on a monthly average basis. The variability of the effluent turbidity is shown in Table 18. At the beginning of the last four months of operation (period 5) it was noted that the turbidimeter had not been properly standardized when making readings. Implementation of the correct standardization procedure accounts for the lower turbidity values during the fifth period. Figure 7 is a frequency distribution of the 332 turbidity values for samples taken in period five. Between 98 and 99 percent of the values were less than the standard of one. The median turbidity was 0.39 FTU.

Microbiological and Disinfection Parameters

Data on the chlorine dosage, demand, and free residual in the effluent are included in Table 19 along with data on the concentration of various pathogenic indicator organisms. The free residual chlorine concentration of 2.23 mg/l and low turbidity of 1 FTU have combined to produce an effluent that consistently meets the EPA Drinking Water Regulations.

Esthetic Parameters

The effluent had no odor when compared to samples of odor free water prepared for the threshold odor test, and exhibited a level of color equal to 3.5 color units based on the platinum - cobalt standard. This data along with the average influent and effluent temperature are shown in Table 20.

Table 17
Suspended Matter

PARAMETER (unit— mg/l)	N*	INFLUENT Arithmetic Mean	Standard Deviation	N	EFFLUENT Arithmetic Mean	Standard Deviation
Turbidity (FTU)	—	—	—	1395	0.884	0.448
Suspended Solids	241	109	21.3	225	1.02	0.954
Volatile Suspended Solids	294	84.0	16.0	—	—	—
Total Solids	—	—	—	209	362	30.4

* N—number of samples.

Table 18
Variability of Effluent Turbidity

4 Month Periods	Number of Samples	Arithmetic Mean (FTU)	Standard Deviation
1	161	0.730	0.256
2	262	0.885	0.800
3	313	1.06	0.464
4	327	1.26	0.520
5	332	0.418	0.182
Total	1395	0.884	—

Table 19
Microbiological and Disinfection Parameters

PARAMETER	N*	EFFLUENT Arithmetic Mean	Standard Deviation
Chlorine Dosage mg/l	2030	4.35	—
Chlorine Demand mg/l	43	1.83	1.62
Chlorine Residual (free) mg/l	57	2.23	1.45
Total Coliforms cells/100 ml	114	0.11	0.39
Fecal Coliforms cells/100 ml	119	0.17	0.50
Pseudomonas Aeruginosa cells/100 ml	36	0.81	1.53
Salmonella cells/100 ml	40	0	0
Total Count cells/100 ml	44	66.8	42.3

* N—Number of samples.

Table 20
Esthetics

PARAMETER	N*	INFLUENT Arithmetic Mean	Standard Deviation	N*	EFFLUENT Arithmetic Mean	Standard Deviation
Temperature (°C)	382	20.9	2.50	320	22.0	2.32
Odor (TON)	—	—	—	35	**N.D.	N.D.
Color (P-C units)	—	—	—	84	3.52	0.37

* N—number of samples.

** N.D.—none detected.

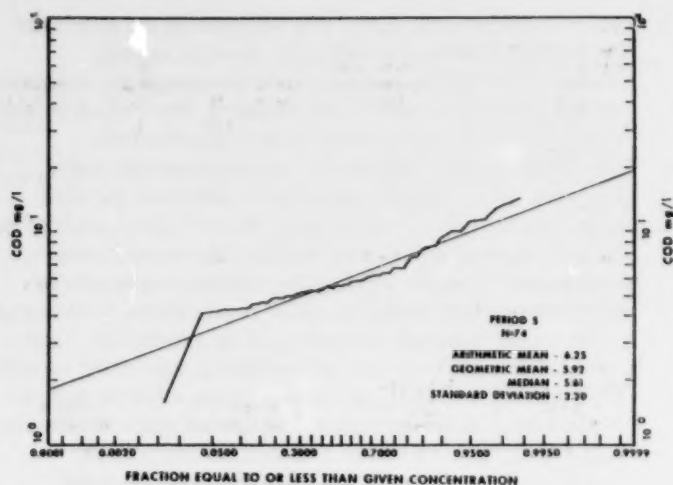


Figure 6.
Frequency Distribution of Effluent COD.

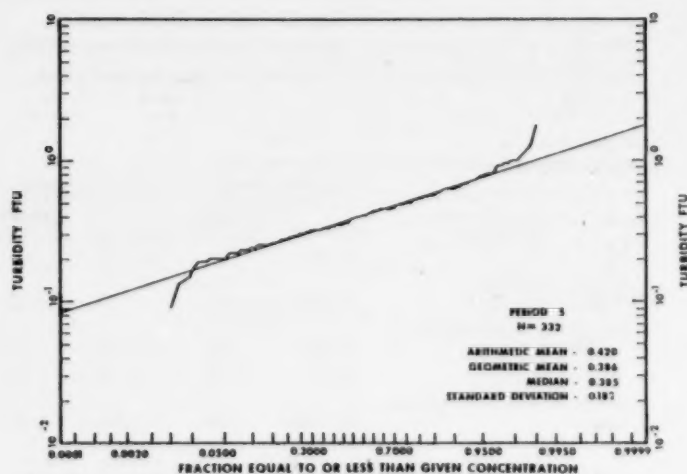


Figure 7.
Frequency Distribution of Effluent Turbidity.

REFERENCES

- "Research Needs for the Potable Reuse of Municipal Wastewater", EPA-600/9-75-007, Dec. 1975.
- Roa, V. C., et al., "A Simple Method of Concentrating and Detecting Viruses in Wastewater", *Water Research* 6: 1565-1576, 1972.
- Wallace, C., et al., "A Portable Virus Concentrator for Testing Water in the Field", *Water Research* 6: 1249-1256, 1972.
- "National Interim Primary Drinking Water Regulations", EPA, Federal Register, Vol. 40, No. 248, Dec. 1975.
- "Preliminary Assessment of Suspected Carcinogens in Drinking Water", Report to Congress, EPA, Dec. 1975.
- Bellar, T. A., & Lichtenberg, J. J., "The Determination of Volatile Organic Compounds at the $\mu\text{g/l}$ Level in Water by Gas Chromatography", EPA-670/4-75-009, Nov. 1974.
- Smith, J. K., et al., "Characterization of Reusable Municipal Wastewater Effluents and Concentration of Organic Constituents", EPA Contract Project No. 68-03-2090 (Final Report in review stage).
- Ames, B. N., et al., *Proceedings of the National Academy of Sciences*, Vol. 70, p. 2281, 1973.
- Jorgensen, J. H., et al., "Rapid Detection of Bacterial Endotoxins in Drinking Water and Renovated Wastewater", *Applied and Environ. Microb.*, Vol. 32, No. 3, p. 347, Sept. 1976.
- Roan, S. G., et al., "Laboratory Ozonation of Municipal Wastewaters", EPA-670/2-73-075, Sept. 1973.
- Sims, P., "Proton Induced X-ray Emission Procedure", Dept. of Physics, Purdue University.

Methods of the Varnish Industry Wastewater Treatment

Vorobyova N.Y., Myasnikov I.N.,
Gandurina L.V., Kedrov Yu.V.

The varnish industry wastewater originates in the process of the production of the varnish resin, varnish, enamel, semiprocessed goods, and also in the process of the washing of the equipment, package, floors, premises. The varnish industry wastewater contains a great amount of dissolved and emulsifiable organic substances, coarse dispersed matter. Pigments, alkali, phthalic and maleate anhydrides and their acids, xylene, toluene, white-spirit, phenol, glycol, acids of the fat row, resinous substances. Besides, the varnish industry wastewater is characterized by the changeable quantitative composition of the pollution, which is determined by the range of the products and the technology of the production. Table 1 gives the characteristics of the two main groups of the varnish plant wastewater. To the first group belong effluents polluted by the coarse dispersed matter. The second group of effluents contains organic substances in dissoluble and colloidal condition. The source of the wastewater pollution is the effluents of separate shops, in particular, of the varnish-boiling shop, of the synthetic resin shop, of the varnish-oil shop, of the package washing shop, of the siccative department. That is why the problem of the treatment of the varnish plant effluents is solved in two aspects: finding the highly effective local methods of the wastewater treatment and working out perfect technological schemes of the treatment of the varnish plant sewage.

Table 1
The Composition of Wastewater of a Varnish Plant

INDICES	THE FIRST GROUP OF WASTEWATER APPROXIMATELY		THE SECOND GROUP OF WASTEWATER APPROXIMATELY	
	BETWEEN	APPROXIMATELY	BETWEEN	APPROXIMATELY
PH	7.4-12	9.6	5.4-8.6	6.7
Roughly dispersed admixtures, mg/l	40-6400	1500	11-300	120
Substances, distracted by chloroform, mg/l	56-810	200	24-400	150
Oil products, mg/l	10-75	40	4-100	30
CUO/chemical use of oxygen, mg/l	400-14000	1500	350-5000	4000

The most effective methods of the varnish plant wastewater treatment are the physico-chemical methods, which meet the following main requirements:

- high efficiency;
- compactness of the structure;
- the simplicity of the construction and its operation;
- an ability to exercise automatic control over the process;
- the technical and economical efficiency of the methods.

To the physico-chemical methods of the wastewater treatment belong:

- settlement
- flotation
- filtering
- chemical fall out
- chemical oxydation
- adsorption by activated coal
- evaporation
- extraction by dissolvents

Thus, the polyester resin industry wastewater treatment includes the settlement from the mechanical admixtures and catalytic oxydation by the temperature of 200–250° C /1/. The copper-chromium contact is used as a catalyst. The purified water is used in the recirculation water supply system. The adsorption method is used mainly to further purify the wastewater, from which suspended and emulsifiable substances were extracted. The activated coal, the peat, the activated anthracite are used as sorbents. The settlement, flotation and seepage are widely used to separate the coarse dispersed matter and also to further purify the wastewater preliminarily treated by coagulants and flocculants. For instance, 50–70% of the coarse dispersed matter can be extracted by the wastewater settlement. The results of the kinetic research /pic. 1/ testify to this.

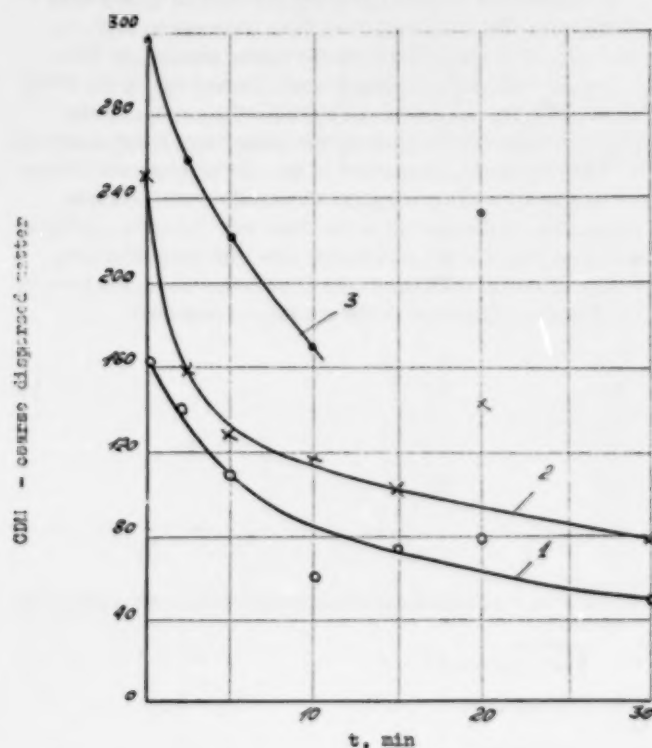


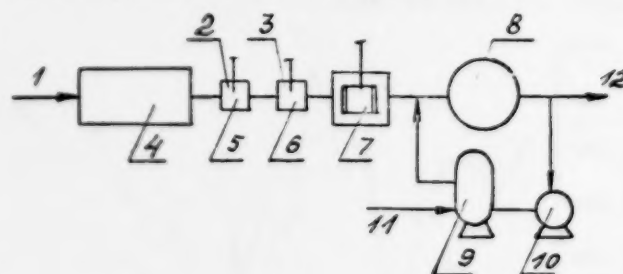
Figure 1.
Kinetics of coarse dispersed matter removal from varnish industry wastes.

To intensify the process of the separation of the coarse dispersed matter the multilayer settlers are used. The use of such settlers makes it possible to greatly intensify the process of clarification, to increase its efficiency. To remove the aggregative-stable colloid pollution, which can not be removed by mechanical settlement, the method of coagulation with the further separation of the coagulated pollution by flotation is used. The example of the use of this very method is the treatment of the wastewater of the industrial amalgamation "Lakokraska". The wastewater treatment on the installation of pressure flotation with the use of sulphate aluminium as coagulant makes it possible to reduce the coarse dispersed matter from 586–920 mg/l to 101–196 mg/l and the substances,

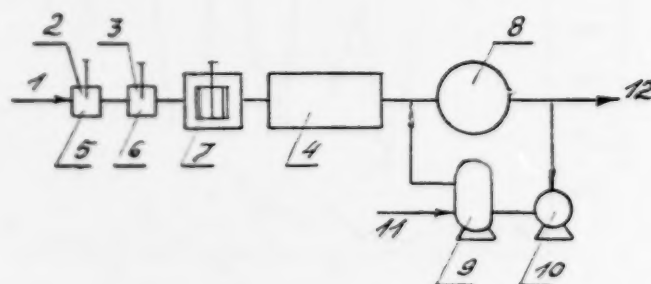
extracted by sulphuric ether, from 140–1408 mg/l to 32–255 mg/l. In the process of the further treatment of the varnish plant wastewater on the flotation-sandy filter the content of the ether-extracted substances reduces to 3–20 mg/l. The quality of such water meets the requirements made to the water used in the recirculation water supply system. It made it possible to reduce the use of the fresh water approximately twice.

The detailed research, held by VNII VODGEO, concerning the problem of the treatment of the varnish plant wastewater by means of the coagulation, settlement and flotation has shown that the efficiency of the treatment depends on the type and dose of the reagent, the place of its lead-in, the mixing up conditions, the flocculation conditions, the concentration of the wastewater pollution.

The best results were achieved when the sulphate aluminium /the dose is 70–150 mg/l/ in combination with the poliacrilamid /the dose is 1–2 mg/l/ used as the coagulant. As the result of the research the optimum schemes of the plant wastewater treatment were chosen. The preliminary settlement with the further treatment of the water by reagents and the separation of the flocculated flakes by means of pressed flotation is necessary for the wastewater, containing a great quantity of the coarse dispersed matter /pic. 2, scheme 1/.



scheme 1



scheme 2

Figure 2.
Principal treatment schemes of varnish industry wastes.

- 1 — influent
- 2, 3 — addition of reagents
- 4 — settling tank
- 5, 6 — mixing chamber
- 7 — flocculation chamber
- 8 — flotation chamber
- 9 — saturator
- 10 — pump
- 11 — air from compressor
- 12 — effluent discharge

The greatest depth of the purification of the wastewater of the II group was reached by the coagulation by the sulphate aluminium together with the poliacrilamid, by the settlement, and further purification on the pressure flotation installation /pic. 2, scheme 2/. The effect of the purification of the wastewater of the I group amounts by the suspended substances to 84-90%, by CUO /chemical use of oxygen/ to 50-80%. The effect of the purification of the wastewater of the II group amounts by the suspended substances to 98%, by CUO to 50-64%.

The specification of the optimum parameters of the physico-mechanical purification of the wastewater was held on the experimental-industrial installation, the capacity of which was 5m³/hour. The experimental-industrial installation includes the reagent economy, multistage thin layer settler and flotation installation, consisting of the flotation chamber of the radial type, the barbotage saturant and the compressor. The flotation installation worked according to the scheme of the single-pass flow /all the water was passed to the saturant/ and recirculation /25% of the purified water was passed to the saturant/. The pressure in the saturant was 5 atm. In the case of the single-pass scheme the reagents were passed before the settler or before the saturant, in the case of these of the recirculation scheme-only before the settler /3/.

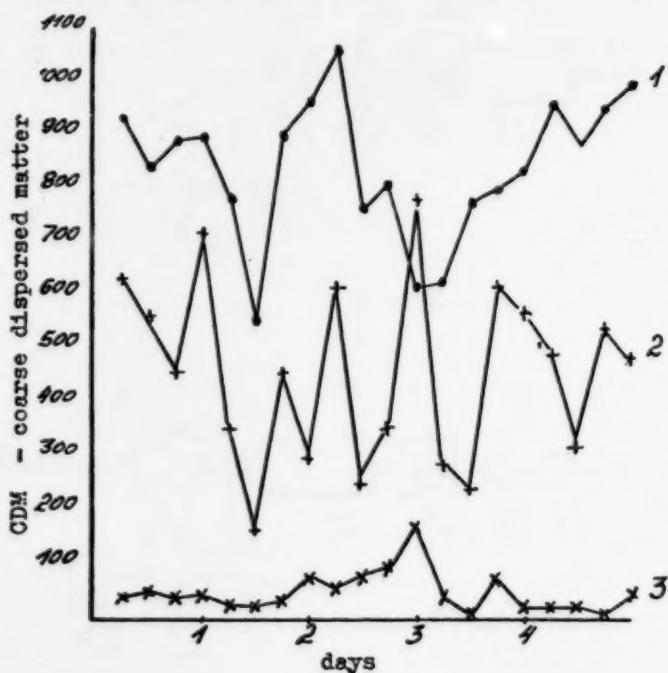


Figure 3.
Curves indicating the decrease in the coarse dispersed matter in the effluent from the pilot-plant installation.

- 1 — influent
- 2 — after settling tank
- 3 — after flotator

The experimental research, carried out on the experimental-industrial installation, made it possible to find out the optimum scheme of the physico-chemical treatment of the package washing shop wastewater. The results are given in Table 2.

One can see, that the maximum effect is reached, when the reagents are passed to the settler and the flotation installation works according to the recirculation scheme. Such scheme provides the best conditions for the mixing up of the reagents with wastewater for flocculation, and the adsorption of pollution on them.

The single-pass scheme of the flotation wastewater treatment when the reagents are passed before the saturant is less effective because of the destruction of the coagulated pollution in the pump or saturant.

In the process of the experimental-industrial tests it was determined that the humidity of foam amounts to 88%, the humidity of the sediment from the settler amounts to 80%.

On the basis of the research work, carried out by the VNII VODGEO, the combined structure for the process of the physico-chemical treatment of the wastewater is suggested /pic. 4/. The mechanical distraction of the coarse dispersed matter, its mixing up with the reagents, flocculation and flotation purification is carried out in this structure. To carry out these processes there is the settlement zone, the zone of mixing before and after settlement, the flocculation zone, the zone of the flotation separation of the coagulated pollution.

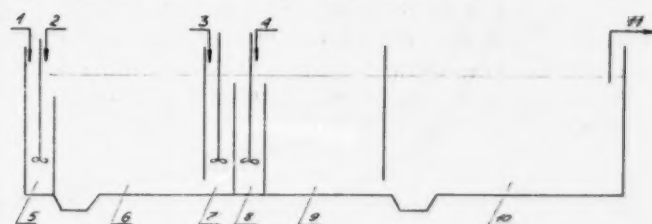


Figure 4.
Scheme of the installation for physical-chemical treatment of varnish industry wastewaters.

- 1 — influent
- 2, 3. — addition of reagents
- 4 — mixing chamber
- 5, 7. — mixing chambers
- 8 — settling zone
- 9 — flocculation chamber
- 10 — flotation zone
- 11 — effluent discharge

Table 2

The Results of the Wastewater Treatment Carried Out on the Experimental-Industrial Installation
HIGHLY DISPERSED ADMIXTURES

THE WORKING REGIME	HIGHLY DISPERSED ADMIXTURES			CHEMICAL USE OF OXYGEN		
	BEFORE TREATMENT MG/L	AFTER TREATMENT MG/L	THE TREATMENT EFFECT %	BEFORE TREATMENT MG/L	AFTER TREATMENT MG/L	THE TREATMENT EFFECT %
1. The single-pass scheme						
a) the reagents are passed before the saturant	114-5080	12-200	69-98	250-1330	240-440	65-67
b) the reagents are passed before the settler	120-3230	15-150	70-99	612-2150	342-1000	30-75
2. The recirculation scheme, when the reagents are passed before the settler	1150-6000	20-100	93-99	1400	110	92

The principle of the clarification of the water in the thin layer is used to intensify the settlement. The process of the clarification is carried out in the shelf nozzle of the single-pass type. The construction of the nozzle provides the even distribution of the flow in it without the use of the special water distributive arrangement. The mixing up chambers and the flocculation chambers are equipped with the mechanical mixers, which make it possible to provide the optimum conditions to carry out the process and to reduce the hydraulic losses.

The flotation chamber of the horizontal type is equipped with the arrangements for the even distribution of the flow in the structure and the arrangements for the distraction of the surface foam and the settled sediment. The combined structure has the equipment for the production and dosing of the reagents, and the feeding of the recirculating expenditure of the water to the flotation chamber.

So, the use of the physico-chemical methods of the purification makes it possible to get the purified water of the required quality, which meets, in most cases, the standards for the reuse of wastewater in the recirculation water supply systems. □

REFERENCES

- A.V. Sacharov, "The wastewater treatment and gas sweetening in the varnish industry," CHIMIYA Publishing House, M., 1971.
- V.S. Narysev, A.F. Stulakova, "The varnish materials and their use," 6, 71, 1974.
- L.V. Gandurina, I.N. Myasnikov, Yu.V. Kedrov, "Chemical and oil machinery engineering," TSINTYchimneftemash, 3, 6, 1977.

Training for Use of Advanced Facilities and Equipment for Wastewater Treatment

Frank P. Sebastian, E. A. Doodeman, John P. Micketts, Envirotech Corporation

Introduction

This paper will address one of the primary reasons for inadequate performance of wastewater treatment facilities: shortages of adequately trained operation and maintenance personnel. It will review some of the training programs and funding currently available through the United States Environmental Protection Agency. It will also describe Envirotech's Environmental Operating Services group method of training new or inexperienced personnel in the operation and maintenance of sophisticated waste treatment equipment and systems. Finally, some specific examples of Envirotech's successful involvement in the training of personnel and operation and maintenance of two sewage plants will be given.

Legislative Background

The Federal Water Pollution Control Act (PL 92-500) established goals for the national water quality program. The Act was amended on October 18, 1972 to add a broad range of authorities and major new programs to further these goals. Since the enactment of PL 92-500 a large amount of federal funds has been invested in new wastewater facilities. The Federal Government and the municipalities had not been providing sufficient funds for operator and management training, however, to operate and maintain these new wastewater facilities. This inadequate funding has created a shortage of competent and qualified personnel at all levels which in turn has led to operating problems of wastewater treatment plants. Therefore, many plants are operating below design efficiency.

Clean Water Report

EPA is required under PL 92-500 to conduct an annual survey and report to Congress on the efficiency of federally funded municipal wastewater treatment facilities. Findings of EPA operation and maintenance inspections and evaluations of existing wastewater treatment facilities are reported each year in the *Clean Water Report* to Congress. The results of the 1973, 1974, and 1975-6 surveys show that one third of all plants are operating below design BOD-removal efficiency. Other deficiencies that have been identified are:

1. Inadequate laboratory testing, controls, and reporting by States and municipalities.
2. Inadequate operation and maintenance management.
3. Unavailability of operation and maintenance manuals for a high percentage of all plants in the surveys.
4. Inadequate training delivery systems.
5. Inadequate inspection follow-up to determine the nature of plant deficiencies and needed assistance.
6. Low level of public awareness of, and support for, improved municipal treatment plant performance.

These problems can virtually all be traced back to shortages of adequately trained operation and maintenance personnel.

In an effort to correct these deficiencies EPA has been conducting several training courses in the wastewater treatment area through intensive one-week programs. EPA has also made

monies available for the construction of State training facilities to train operation and maintenance personnel. Additionally, EPA has awarded several grants to the states, universities and other training institutions to support operator training, as well as training for treatment works operations and maintenance. Grants awarded under Section 104 of the Water Pollution Control Act represent a large part of EPA's funding to help states and local governments in their training programs. EPA has also been successful in having monies allocated by prime sponsors under the Comprehensive Employment and Training Act of 1973 for the employment and training of persons in the water and wastewater fields.

EPA Guidelines

In recognition of the need to place increased emphasis on the effective operation of new waste treatment facilities constructed with Federal grant monies, EPA in September of 1976 published guidelines to permit federal funding of sewage treatment plant start-up costs. The following start-up services were identified as eligible for Federal funding:

1. Training of plant operation and maintenance personnel necessary to operate specific treatment processes used in the facility.
2. Providing expert operational assistance for adjusting and "fine tuning" of the treatment process and equipment to optimize performance, safety and reliability under actual operating conditions.
3. On-site training and instruction of plant personnel to insure that the sampling and laboratory testing needs are fully understood.
4. Training of the operation and maintenance staff to insure establishment of a maintenance management system as outlined in the plant's operation and maintenance manual.
5. Training of plant personnel to insure implementation of a records management system as detailed in the operation and maintenance manual.
6. Revision of the operation and maintenance manual based on actual operating experience obtained during the start-up period.

To be eligible for Federal money, the start-up services must be provided by the grantee's consultant or appropriate manufacturer or vendor. Subagreement covering start-up services would be prepared on a direct cost reimbursable basis.

Funding of start-up services would generally be available for two to three months, the guidelines say. For large or complex systems where several seasons are needed to determine plant performance, however, funding may be allowed for twelve months. Grant eligible start-up services are expected to average 90 man-days but provisions for up to 300 man-days have been made depending on the size and/or complexity of the plant.

Federal start-up funds would not be available for entry-level training or operator improvement training. Cost of *off-site* training and/or orientation programs would also be ineligible for federal funding. Normal operating and maintenance costs of the municipal waste treatment facility, as well as wet and dry equipment facility testing, are not grant eligible either.

Envirotech's Environmental Operating Services

Recognizing the lack of consistent performance of solids handling systems and advanced wastewater treatment processes, Envirotech formed an Environmental Operating Services Group which assumes complete responsibility for start-up assistance, operator training and maintenance control to insure equipment start-up and performance to design standards.

The Operating Services group provides the technical expertise necessary to start-up, operate and maintain wastewater treatment plants. In providing a link between design and operation Operating Services can reduce start-up problems; maintain plant operations at required performance levels; build a trained team of knowledgeable, skilled operators; reduce operating costs; and increase equipment life. These results are accomplished through implementation of an organized training program. Appended to this paper is a step-by-step training program outline which has been used successfully by Envirotech in training personnel for the operation of advanced sludge processing equipment.

The Operating Services operations coordinator, supported by process, equipment, and computer experts, can provide the following services:

1. Rapid "on-stream" operations.
2. Consistent and optimum process performance.
3. Computerized management information systems to monitor and analyze unit processes performance, budgets, manpower allocation, and equipment maintenance.
4. On-site personnel training for up to one year, including classroom training; laboratory training; simulated safety and emergency drills; computer training; testing and evaluation of the operator's aptitude, performance and progress; and demonstration of preventive maintenance programs.
5. Documentation, including step-by-step procedures based on twelve months of actual performance.

The advantages of the Operating Services training program are many. They include:

1. Protection of EPA investment through
 - A. Effective preventive maintenance program day one
 - B. Early achievement of design capacity
 - C. Avoidance of consequence or trial and error learning.
2. Achievement of effluent quality on routine basis by
 - A. Liquid treatment objectives
 - B. Air pollution requirements
 - C. Avoidance of by-pass, upsets and odors
3. Optimization energy and fuel consumption by
 - A. Dewatering and incineration system
 - B. Wet encl./dry encl. balance.

There are additional advantages to the one-year Operating Services training program as compared with the three or six months program:

1. Allows greater sewage loadings due to collection systems completion.

2. Provides the seasonal variations to be encountered.
3. Allows initial personnel turnover which occurs during the first three months.
4. Provides an adequate period of debugged operation.
5. Allows for critical annual maintenance activities not available within six months.
6. Cost approximately 30% more than six months program.

Case Histories

In the State of California Envirotech's Environmental Operating Services training programs have helped treatment plants in the City of Burlingame and the Fairfield-Suisun District meet air quality standards set by the State and the Bay Area Air Pollution Control District, respectively.

The Burlingame plant was originally installed in 1934 and upgraded in 1968 to provide secondary treatment and a partial effluent polishing. The State's effluent quality standards were not consistently met by the city's sewage treatment plant. One of the major problems the city was faced with was the lack of personnel experienced in the operations of advanced wastewater treatment facilities.

The city decided to bring the Operating Services group in to resolve its manpower shortages and bring the sewage treatment plant's operations up to standards. They were able to bring about a 51% and 27% improvement in the BOD and SS removals, respectively, and an 89% reduction in the effluent coliform count.

This was accomplished by first of all transferring most of the plant's staff to Envirotech's payroll. The field team was supported by a home-office group which had computerized data analysis and reporting procedures at its disposal. A computerized preventive maintenance program was developed which gave thorough attention to tight process control. The city adopted several recommendations which resulted in upgrading several unit operations, such as: repair of the primary clarifier; alteration of the primary clarifier grease skimmer and pump station operations; modification of the primary sludge wasting schedule; adjustment of the mechanical aerators; and revamping and unfreezing of the sludge uptake tubes in the final clarifier.

Finally, the Operating Services group was able not only to resolve the plant's manpower shortages and bring the plant's operation up to design standards, but plant performance actually exceeded the consultant's design criteria.

In January 1974 the Fairfield-Suisun District signed an operation and maintenance contract with Envirotech for seventeen months in an effort to solve some of the major problems that were plaguing the District's sewer plant. For example, the plant consistently failed Bay Area Air Pollution Control District limitation tests; exhaust scrubber emissions were exceeding standards by 300%; and the plant was unable to handle the sludge volume and extremely foul smelling.

The plant's operating staff was transferred to Envirotech's payroll. Trouble areas were identified and plans for corrective action were developed. Fine tuning adjustments and improvements to reduce emission proposed by the operations and maintenance group were made, and, as a result, the plant

was able to meet Air Pollution District standards. The solids handling problem was resolved by clearing blocked sludge lines and eliminating recycling of scrubber ash. These and other improvements resulted in a 48% increase in solids handling capacity, and the plant was able to incinerate all sludge on a 40-hour week schedule rather than operate a 90-hour schedule. Dramatic improvements were also accomplished in the efficiency of the oxidation ponds. Performance objectives were met and improved efficiency will protect the equipment life. A Fairfield-Suisun Sewer District Board member had the following to say about the results of the operation and maintenance contract: "Rather than abrogating our responsibility as sewer board members, the decision to use an external operations and maintenance service has given us greater executive control. No longer embroiled in day-to-day operational problems, we can turn our attention to the major policy considerations and long-range planning necessary to assure the welfare of our citizens."

Conclusion

As mentioned earlier, the effective operation of a wastewater treatment plant depends on the knowledge, experience and general capabilities of its personnel. Furthermore, both EPA and private industry recognized the need to place increased emphasis on the effective operation of new waste treatment facilities constructed with Federal grant funds. The EPA directive that permits federal funding of sewage plant start-up costs has gone a long way toward establishing a more effective transition from construction to operation of new wastewater plants. In this same connection, Envirotech's Environmental Operating Services program has proven to be highly successful in the training of treatment facility staff and the complete plant operation and maintenance. All plants operating under Envirotech direction have met State effluent quality requirements since the beginning of operational responsibility. In addition, with proper operations and a daily on-the-job training program operating costs are reduced, improved operating performance is achieved, along with increased equipment life. □

Methods of Improvement of the Secondary Settling Tanks Operating Efficiency

Skirdov I.V., Koltsova S.I., Morozova K.M.

Secondary settling tanks of various types are widely used in the system of facilities for biological treatment of waste waters.

They perform several functions: separation of mixed liquor, clarification of supernatant and thickening of settled sludge. These functions must be interrelated in such a way as to ensure the necessary degree of the returned sludge thickening sufficient for maintaining a given concentration of biomass in aeration tanks at the lowest content of the effluent solids.

All other conditions being equal (such as the sludge volume index (SVI), the sludge concentration in the aeration tank, and the wastewater temperature) SS concentration in the effluent depends on the hydraulic conditions in the settling tank ensured by the type of sludge distributing and water collection devices.

In practice of the treatment facilities construction in the USSR vertical, rectangular and radial settling tanks are employed. Schemes of these facilities are given in Fig. 1. Vertical settling tanks are used at designing the treatment facilities of low capacity while radial and rectangular ones are used at aeration stations of medium and high capacity. Radial settling tanks are practiced on the largest scale; they are reliable in operation, sludge suckers or sludge scrapers provide systematic sludge removal from the unit. However, radial settling tanks have unsteady turbulent conditions subjected to the influence of density and convective flows. These disadvantages of radial settling tanks become redoubled during separation of mixed liquors which density is higher than that of the effluent in the settling tank.

Studies of hydraulic conditions of radial secondary settling tanks were carried out at the Institute "VODGEO" during investigation of a number of municipal and industrial treatment facilities using the method of tracing by a fluorescent and a radioactive isotope. The analysis of the obtained data permitted an evaluation of the degree of hydraulic imperfection of settling tanks. For radial settling tanks 20-40 m in diameter the efficiency of the volume usage expressed by the relationship between actual and designed retention time is equal to 0.3-0.45. It means that 55-70% of the settling tank's volume are occupied by practically stagnant zones.

Distribution of SS concentration in the settling tank's volume (see Fig. 2), when in the central part SS concentration is 2-3 times lower than in the working flow from the settling tank, and is indicative of the imperfection of hydraulic conditions. It indicates that the upper central part is semi-stagnant. The working flow is carried by the density flow down to the bottom and, when moving towards the periphery, occupies approximately $\frac{1}{3}$ of the tank's volume. Having reached the edge of the tank at a high speed the working flow reflects and generates the intensive circulation and the counter flow in the upper part of the settling tank. In the vortex zone under the collecting weir the increased SS concentration is observed, with some part of SS being carried out with the effluent.

Density flows also render a pronounced effect on the hydraulic conditions of vertical settling tanks. Having entered the unit mixed liquor is spreading about the more thickened sludge blanket, strikes against the edge and generates a circular flow, which rapidly reaches the surface of the settling tank, and the working flow overflows into the collecting trough. The

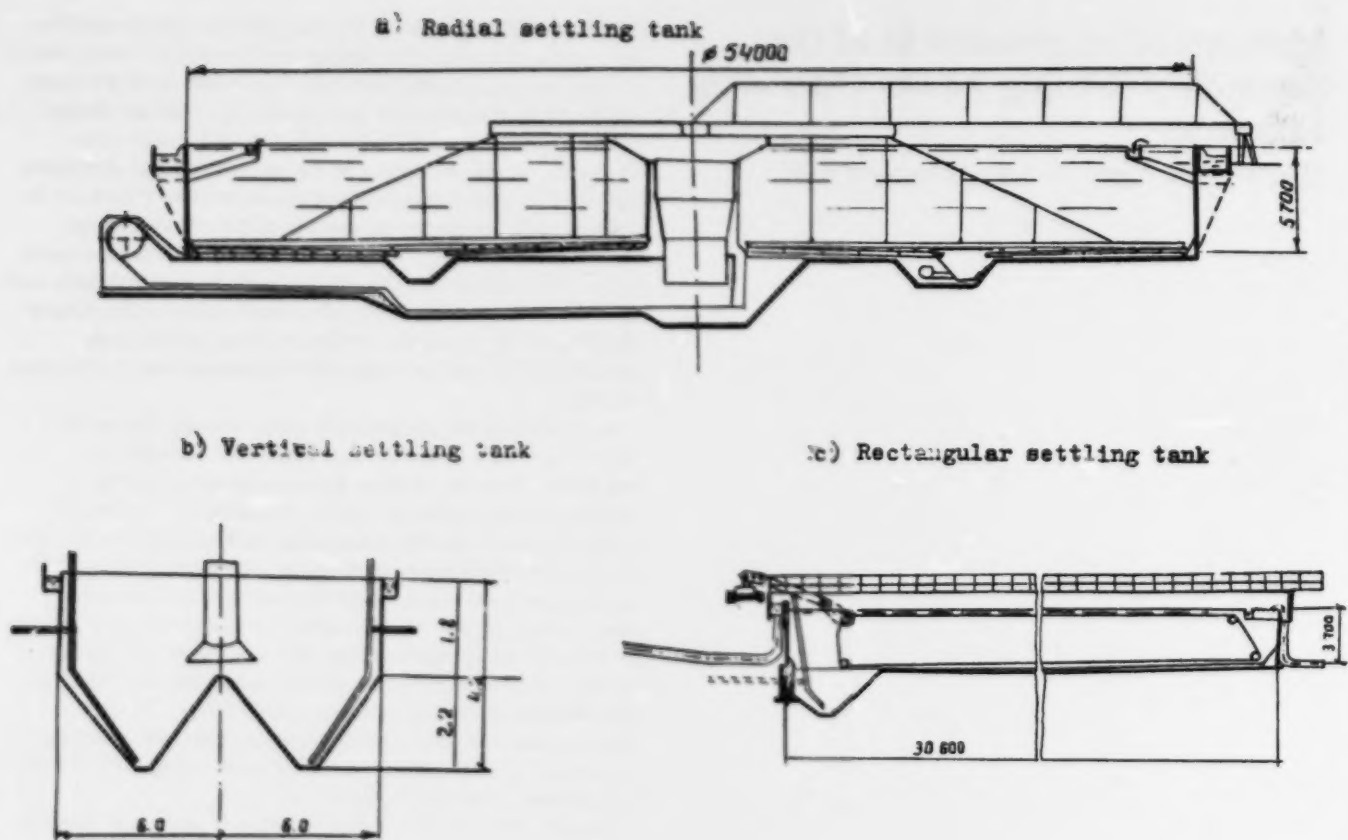


Figure 1.
Diagrams of secondary settling tanks.

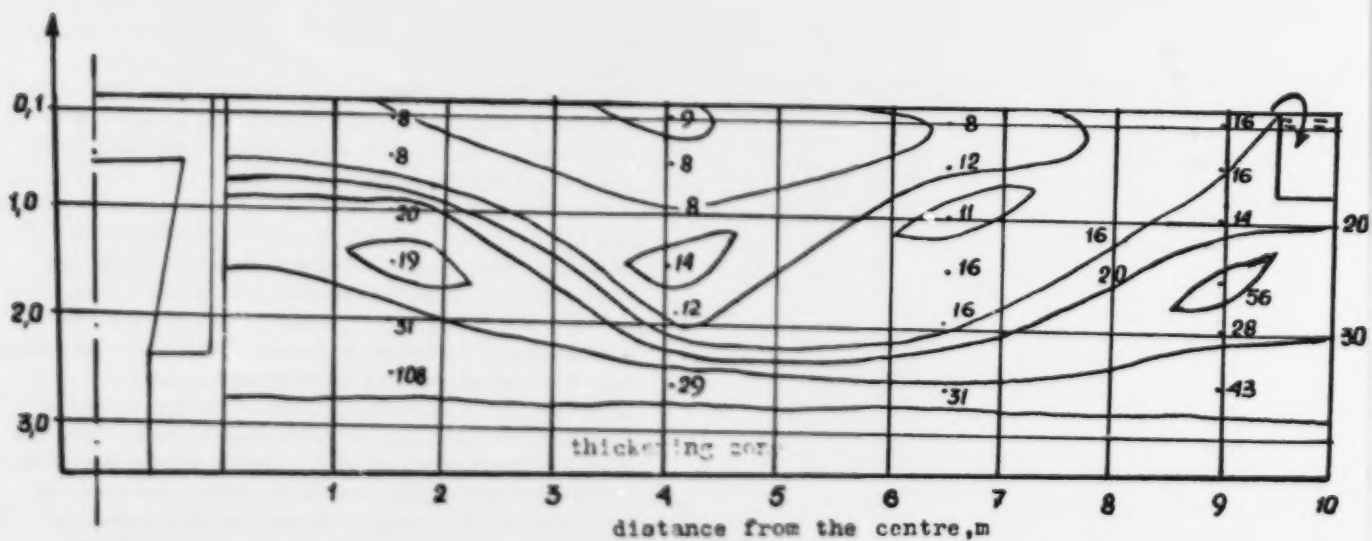


Figure 2.
Field of concentrations in a radial settling tank. $D = 20$ m.

efficiency of the volume usage of vertical secondary settling tanks is equal to 0.25–0.3. The characteristic feature of standard constructions of these facilities is the sludge deposition on the slopes and in the corners of sludge hoppers which sufficiently hampers the maintenance.

To a certain extent the negative effect of density flows is characteristic of rectangular secondary settling tanks.

Drastic improvement of hydraulic conditions of secondary settling tanks is possible by two ways: 1) by reduction of the difference between densities of feeding mixed liquor and detained influent in the settling tank and 2) by employment of rotating sludge distributing devices when the density flow is eliminated by the velocity of the distributing device moving in the opposite direction. The first method can be realized by mixed liquor feeding directly into the sludge blanket.

After preliminary researches carried out on the model of the settling tank this method was verified at one of the operating secondary settling tanks installed at treatment facilities of a chemical complex. With this purpose one of the conventional settling tanks was transformed into a tank with the rotary bottom distributing device and developed surface water-collecting device. The scheme is given in Fig. 3. Mixed liquor is fed by means of a sag pipe 1 to the central rotating chamber 2. The chamber is connected with two sludge distributing pipes located near the bottom of the tank. Sludge distributing pipes

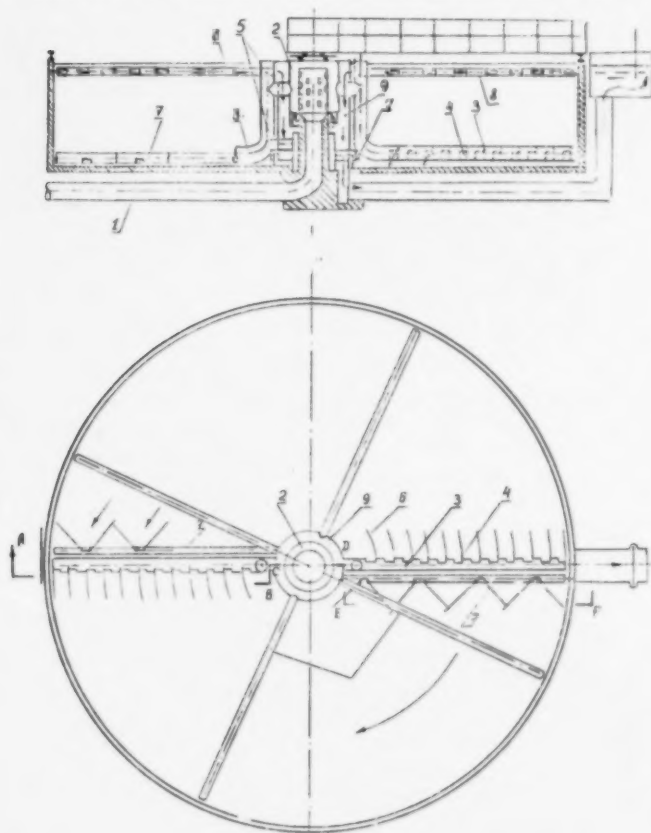


Figure 3. Settling tank with the rotating sludge-distributing device and developed water collecting device.

are provided with outlets 4 near which jet-cutting segmental diaphragms 5 are installed. Jet-guiding blades 6 are fixed on the pipe behind the outlets. Thickened and settled activated sludge is collected by two sludge suckers 7.

The clarified effluent collection is realized by four radially located submerged pipes 8 connected with the rotating central chamber 9 for clarified water. Rotating parts of the central chamber are conjugated with the lower parts by means of air valves 5 constantly fed by air. The excess air is discharged to the atmosphere through special pipe sockets. The design of water collecting and sludge distributing devices provides equal detention time of each separate jet. Rotation speed of the sludge sucker is 17.5 rev/min.

The settling tank with the rotating bottom distributing device operates steadily at the variations of the hydraulic conditions from 0.5 to 2.1 m/h. Effluent solids do not exceed 10 mg/l. Within the period of investigations the sludge concentration in the aeration tank varied from 1.1 to 1.6 g/l and the SVI was equal to 96–166 cm³/g. The highest load by the solid phase was 3.2 kg/m² hour.

Studies of hydraulics and the field of concentrations have shown the absence of density flows in the settling tank. The efficiency of the settling zone usage is 0.85–0.95.

The automatic system of stabilization of sludge and water levels in the settling tank sufficiently simplifies the maintenance of the unit.

The investigations and the experience of the radial settling tanks maintenance proved the presence of semi-stagnant zones (in the central part of the unit) and vortex zones with high velocities caused by the effect of density flows. These phenomena were studied at radial settling tanks of various diameters: 20, 24, and 40 m. The SS concentration in the central part of the settling tank is 2–3 times lower than in the effluent. The same situation was observed during investigations of vertical settling tanks.

Technological parameters of operation of various secondary settling tanks may be compared by using the following relationship:

$$C_t = f(q_r, I C_a).$$

where C —effluent solids, mg/l

I —sludge volume index, cm³/g

C_a —sludge concentration in the aeration tank, g/l

Product IC_a is the generalized criterion characterizing settling properties of various activated sludges. The graphical form of this relationship for secondary settling tanks is given in Fig. 4. It is seen from the Figure that the settling tank with the bottom distribution is the least subjected to the influence of the hydraulic load variations. These facilities steadily operate within the load range from 0.1 to 0.48 m³/m² hour while the other types of facilities at the normal effluent solids do not bear the loads higher than 0.2–0.3 m³/m² hour.

Higher operating data of settling tanks with the bottom distributing device are ensured by the peculiarities of their hydraulic conditions which make the conditions of turbulent and gravity agglomeration close to optimum ones. These facilities can be used with high MLSS concentrations (3–5 g/l) when the effect of density flows becomes very considerable.

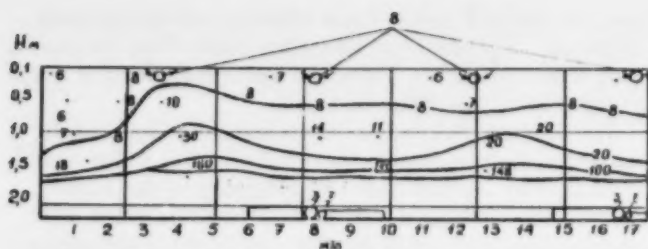


Figure 4.
Field of concentrations in a settling tank with the bottom distribution.

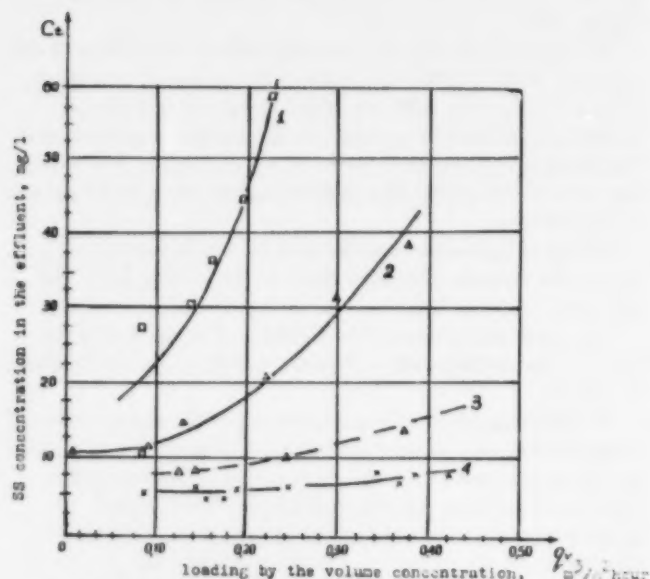


Figure 5.
Sludge content in the effluent from secondary settling tanks of various types depending on loading by the volume concentration.
1—vertical settling tanks. 2-3—radial settling tanks
4—settling tank with the bottom rotating distributor.

Conclusions

1. The hydraulic conditions of the secondary settling tanks significantly affects their efficiency of operation. Due to the density flows in vertical and rectangular settling tanks the efficiency of the volume usage does not exceed 40%.
2. Elimination of density flows with the help of rotating distributing devices will permit to increase the efficiency of the volume usage up to 80-90%, the highest effect can be reached by using bottom rotating distributing devices.
3. Improvement of hydraulic conditions of secondary settling tanks will permit to increase their capacity. Thus the hydraulic load on settling tanks with the bottom rotating distributor reaches $2.2 \text{ m}^3/\text{m}^2/\text{hour}$ at normal effluent solids up to 20 mg/l which exceeds the load on radial settling tanks almost 2 times.
4. Operation of new secondary settling tanks was tested under full-scale conditions. These facilities are recommended for installation at a number of treatment plants. Their use at treatment plants with capacity of $100,000 \text{ m}^3/\text{day}$ will give the economic benefit of 140,000 rubles per year. □

Contractor Evaluation for Ozonation of Wastewater

Edward J. Opatken,
Albert D. Venosa,
Mark C. Meckes,
EPA

Ozone is now in use as a wastewater disinfectant. Up to 1974, chlorine was used exclusively for disinfecting wastewaters within the United States. Since that time, Indiantown, Florida has practiced disinfection with ozone, a little later Woodlands, Texas, and recently Estes Park, Colorado. The Meander Water Pollution Control Facility, near Youngstown, Ohio, is undergoing start-up of an ozone disinfection process and there are several facilities under construction and a considerably larger number under design. But if we look closely at the first four systems I mentioned, three in practice and one undergoing start-up we find that each system has a contractor that differs from the other three. Each system is looking for that economic edge that will place it in an advantageous position in regard to its competitors.

And I agree that there are significant economic and sales benefits that can be reaped from an optimum gas/liquid contactor. The problem is to determine reliably which contactor yields the most economical system for ozone application.

A project was initiated at the Robert A. Taft Center in Cincinnati to evaluate general type liquid-gas contactors. Five generic contactors were selected as representative of typical gas-liquid devices. These contactors are:

Gas-Liquid Contactors

1. Packed Column
2. Jet Scrubber
3. Bubble Diffuser
4. Pressure Injector
5. Turbine Agitated Reactor

Four of the above five contactors are in use today. The packed column is at Woodlands, TX, the bubble diffuser at Estes Park, CO, the pressure injector at Meander, and the stirred reactor at Indiantown, FL.

With the selection of these contactors, ground rules were established to insure that a comparative evaluation will be conducted with minimal bias. These rules are:

1. The liquid flow will be fixed at 75 l/min and the 5 contactors will be designed for this liquid flow rate.
2. Parallel evaluation—the same quality wastewater effluent will be fed to the contactors at the same time, to neutralize the effect of a changing wastewater.
3. Four contactors will be evaluated against the same contactor, in our case, the packed column was designated as the standard and performance will fall above or below the standard.
4. Experiments will treat both contactors alike, that is, same ozone dosage, same ozone concentration, same gas and liquid flows.
5. Performance evaluation will include ozone transfer, ozone utilization and reduction of total and fecal coliforms.

Lets now look at a flow schematic of the pilot plant, and follow the wastewater as it flows through the system.

During the first few months of the project, effluent from the Muddy Creek Wastewater Treatment Plant served as the wastewater source for the ozone disinfection studies. This plant, operated by the Metropolitan Sewer Board of Greater

Cincinnati, is a conventional activated sludge system treating approximately 57,000 m³/day of domestic wastewater.

On the day of an experiment, 20 m³ of Muddy Creek effluent were drawn into a tank truck and transported to the pilot plant. The effluent was pumped from the tank truck and split into two lines. Both lines were suitably valved to allow for any desired flow configuration. One line passed through a rotameter and control valve and finally into the top of the packed column. The second line was fed into a pump, where the pressure was boosted to 380 kPa. The wastewater then flowed through a rotameter and into the jet scrubber.

Using the above mode of operation, an entire series of experiments were performed on each contactor separately. This experimental arrangement, which was essentially a batch operation, permitted the same wastewater to be pumped to each ozone contactor without the need for parallel, simultaneous operation.

Secondary effluent was also obtained from the conventional activated sludge pilot plant located at the Robert A. Taft Laboratory. The raw wastewater entering the plant was of mixed industrial and domestic origin. Effluent from the final clarifier was split between the two contactors simultaneously and the flow was monitored by rotameters. An optional multimedia pressure filter was available for removing suspended solids from the effluent prior to splitting the flow. Data obtained under this arrangement were collected with both contactors operating in parallel as specified in the ground rules.

Ozone Generation

The ozone generator was capable of producing ozone at a maximum rate of 3500 mg/min. Since the pilot facilities were designed for evaluating two contactors in parallel, the maximum applied dosage per contactor was approximately 25 mg/l.

Service air from the Robert A. Taft Laboratory, supplied at a pressure of 620 kPa, served as the source of air for ozone generation.

The air was filtered for removal of particulates and lubricants, then dried by adsorption of water vapor on activated alumina. The dryer consisted of two parallel dryer beds, each containing 8 kg of activated alumina. The process air was passed through one of the dryer beds, where the dew point was lowered to -70° C. Approximately 15 percent of the dried air was returned for regenerating the alumina in the other dryer bed. The dryers then automatically reversed their functions, placing the regenerated bed on line for drying air while the other bed underwent regeneration. The dried air was then filtered for removal of any carry-over adsorbant and monitored for dryness by an in-line dew-point meter.

The dried air was reduced in pressure from 620 kPa to 60 kPa and then split into two lines, each equipped with a rotameter and valve for flow control between 75 and 500 l/min. The gas then entered the dual ozonator, which was air-cooled and contained six plates per unit. Power was applied between 200 and 2000 watts, depending upon the ozone concentration and air flow desired for the particular experimental run. The temperature of both ozone-enriched gas streams were measured upon exiting the ozonator. The two streams were recombined

to obtain a homogenous mixture and then split before entering rotameters with a range between 20 and 130 l/min. After the rotameters, separate gas lines fed the packed column and the jet scrubber.

Packed Column

The packed column was a 230 mm diameter glass column 3.1 m in length. The packing consisted of either 13 mm or 25 mm ceramic intalox saddles. A teflon redistributor plate was located midway in the column to redirect the liquid towards the center of the column. Secondary effluent entered the top of the column and exited at the bottom. The residence time of the secondary effluent was 20 seconds at a flow rate of 75 l/min. Ozone was injected at the bottom of the column, flowed upward and countercurrent to the secondary effluent, and exited at the top. Pressure taps were located in the gas line at the bottom and top of the column for determining the differential gas pressure during an experimental run.

Jet Scrubber Contactor

The jet scrubber was a stainless steel liquid-gas contactor in which secondary effluent was pumped through an orifice into a 300 mm diameter chamber. The resulting pressure drop of 380 kPa caused minute droplets to form. The ozone entered near the orifice and both components (secondary effluent and ozone) flowed concurrently down the chamber. The combined stream then flowed to a bottom outlet where the contacting gas was separated from the effluent. A portion of the gas was aspirated back into the upper chamber by the liquid flowing through the orifice and recycled to the inlet area.

Ozone Decomposer

The exhaust gas from each of the contactors was directed to an ozone decomposer. An electric heater was used to increase the exit gas temperature to between 260° C and 290° C to insure destruction of the ozone in the off-gases.

Sample Collection

Gas Samples

Ozone gas sampling ports were located at the outlet of the ozone generator, the exhaust gas line from each contactor, and the exit gas line following the ozone decomposer.

A grab influent gas sample was collected and analyzed iodometrically at the start of an experiment. Continuous measurement of ozone in the gas stream was made subsequent to the grab analysis to provide assurance of a steady state ozone concentration. The continuous monitoring was accomplished by a Dasibi ozone analyzer.

Wastewater Samples

Valved sampling ports were located on the influent and effluent lines of both ozone contactors. Samples were analyzed for chemical characterization of the effluent before and after ozonation. Bacteriological samples were tested for total and fecal coliforms by the MPN method.

Chemical and Physical Characterization of Wastes

Total chemical oxygen demand (TCOD), soluble chemical oxygen demand (SCOD), total organic carbon (TOC), total suspended solids (TSS), volatile suspended solids (VSS), ammonia nitrogen ($\text{NH}_3\text{-N}$), total Kjeldahl nitrogen (TKN), manganese (Mn), iron (Fe), pH, and turbidity were determined. Nitrate nitrogen (NO_3) and nitrite nitrogen (NO_2) were also determined.

The surface tension of the wastewater before and after the contactors was determined by the ring method using a DuNouy type tensiometer. Viscosity was determined with the Cannon-Fenske viscometer.

Determination of Mass Transfer Coefficients

Mass transfer coefficients in the packed column and jet scrubber were determined using MCWTP effluent. Ozone was contacted with the secondary effluent in the packed column and jet scrubber. Gas flow rates were varied between 35 and 150 l/min. The liquid flow rate was held constant at 75 l/min, and the ozone concentration was measured in the inlet and exhaust gases, and in the liquid emerging from the contactors.

The quantity of ozone that can be absorbed by the secondary effluent was related to the inlet ozone gas concentration and Henry's constant. This relationship is described by the following equation:

1. Partial Pressure of Ozone in Equilibrium with Dissolved Ozone

$$y^* = Hx$$

where y^* = partial pressure of ozone in the gas in equilibrium with the dissolved ozone in the liquid (mm Hg)
 H = Henry's constant (mm Hg/mol fraction of ozone in the liquid)
 x = ozone concentration in the secondary effluent (mols O₃/mol liquid).

Henry's constant defining ozone solubility in water was obtained from the International Critical Tables. Since the units on Henry's constant were tedious to manipulate, they were converted at various temperatures from mm Hg/mol fraction of ozone in the water to liters water/liter air. The magnitude of Henry's constant is substantially affected by temperature, as shown in the next slide.

The mass transfer coefficients for the packed column were determined using the following equation:

2. Mass Transfer Coefficient

$$N = G(y_1 - y_2) = K_g V a (\Delta y_{1m})$$

where N = ozone transferred from the gas phase into the secondary effluent (mg/min)
 G = gas flow rate (liters gas/min)
 Y_1 = ozone concentration in the inlet gas (mg/l)
 Y_2 = ozone concentration in the exhaust gas (mg/l)
 $K_g V a$ = overall mass transfer coefficient (liters gas/min)
 Δy_{1m} = log mean concentration difference of ozone in the gas phase across the entire column (mg/l).

The term Δy_{1m} is defined by the following equation:

$$\Delta y_{1m} = \frac{(y_1 - y_1^*) - (y_2 - y_2^*)}{\ln \frac{(y_1 - y_1^*)}{(y_2 - y_2^*)}}$$

where y_1 = ozone concentration (mg/l) in the gas phase in equilibrium with ozone residual in the liquid at the bottom of the column, as defined by Henry's Law

and y_2^* = ozone concentration (mg/l) in the gas phase in equilibrium with ozone residual in the liquid at the top of the column since the incoming wastewater had no ozone residual, $y_2 = 0$ in the above equation.

The mass transfer coefficients for the jet scrubber were computed in the same manner. However, since the flow configuration in the jet scrubber was concurrent rather than countercurrent, $y_1^* = 0$ because the liquid entering the contactor contained no ozone residual. Thus, for the jet scrubber, the equation for the log mean concentration difference simplifies to:

$$\Delta y_{1m} = \frac{y_1 - (y_2 - y_2^*)}{\ln \frac{(y_1)}{y_2 - y_2^*}}$$

The mass transfer coefficients for both contactors are illustrated in the next slide. The data indicate that the mass transfer coefficients for the packed column were more than twice the value determined for the jet scrubber at the gas flow rates studied. Henry's Law states by definition, that as ozone residual increases, the ozone concentration in the gas phase in equilibrium with the residual will also increase. This means that transfer is inhibited by high ozone residuals. A countercurrent flow configuration, such as in the packed column, has the advantage not only of contacting the liquid containing the highest ozone residual with the gas containing the highest ozone concentration (i.e., at the bottom of the column), but also of contacting the liquid containing the least ozone residual with the gas containing the lowest concentration of ozone (i.e., at the top of the column). This tends to equalize the concentration driving force and thus maintain a more uniform mass transfer rate across the entire length of the column.

In contrast, the jet scrubber, which operates in a concurrent flow configuration, maintains a high concentration gradient at the inlet end. As the residual increases, the exit gas concentration, which must be in equilibrium with the residual, will also increase. This substantially limits ozone utilization in the jet scrubber when compared with the packed column.

Both contactors had relatively short liquid contact times (approximately 20 seconds for the packed column and 3 seconds for the jet scrubber, at a wastewater flow rate of 75 l/min). This tended to hinder both mass transfer and ozone utilization. Longer contact times would permit the dissolved ozone to react with oxidizable constituents in the secondary effluent, lowering the ozone residual and thus increasing the overall ozone concentration driving force.

Ozone Utilization

Ozone utilization is defined by the following equation:

3. Percent Ozone Utilization

$$\% \text{O}_3 \text{ Utilized} = \frac{Y_1 - Y_2}{Y_1} \times 100$$

where y_1 = ozone concentration in the influent gas (mg O₃/l)
 y_2 = ozone concentration in the exhaust gas (mg O₃/l).

The next slide summarizes the percent ozone utilization data in both contactors as a function of applied ozone dose. Results indicate that the percent ozone utilized by the packed column was substantially greater than the jet scrubber. Thus, the packed column was superior to the jet scrubber from the standpoint of mass transfer coefficient and percent ozone utilization efficiency.

Ozone Concentration

Dosage is defined as:

4. Applied Ozone Dosage

where $D_a = y_1 G/L$,
 y_1 = ozone concentration in the inlet gas (mg O_3 /l gas)
 G = gas flow rate (l_{gas}/min)
 L = liquid flow rate (l_{liq}/min)

There are two ways to vary ozone dosage: (1) change the G/L ratio while maintaining a constant gas concentration, or (2) change the ozone gas concentration while maintaining a constant G/L ratio. Ozone utilization will vary in the same manner. However, utilization can also be changed by maintaining dosage constant and increasing the concentration of ozone in the gas (i.e., increase y_1 and decrease G/L). Figure 15 illustrates the change in percent ozone utilization in both contactors as a function of y_1 at a constant dosage level. It is clear that as G/L decreased (or y_1 increased), percent ozone utilization increased, even though the applied dosage was constant. Caution must be exercised in using these data, because increased y_1 values require increased power input per unit weight of ozone when the dosage is constant. Thus, power must be factored into any evaluation to establish optimum performance criteria. The most cost-effective operating condition for ozone disinfection does not necessarily comprise the lowest ozone dosage.

Effect of Packing Size on Packed Column Performance

After completing Phase I of the investigation, it was necessary to switch from the MCWTP effluent to the R. A. Taft Laboratory pilot plant effluent so that both contactors could be operated in parallel and simultaneously. The overall quality of the latter effluent was inferior to the MCWTP effluent. This factor resulted in excessive pressure drops in the packed column when the system was operated at a liquid flow rate of 75 l/min.

To compensate for the increased pressure drops in the packed column, it was necessary to increase the packing size from 13 mm to 25 mm ceramic intalox saddles. This modification, in effect, lowered the surface area of the packing and consequently enabled operation of the column at more reasonable pressure drops (i.e., <30 cm H_2O). However, this also affected the mass transfer efficiency of the column. Table 1 demonstrates the effect of packing size on the overall mass transfer coefficients of the packed column at various gas flow rates.

The overall mass transfer coefficient ($K_g V_a$) consists of the product of the mass transfer coefficient ($K_g V$) and the surface area per unit volume of packing (a). Although the $K_g V$ did not change with packing size, the total mass transfer of ozone into

the liquid over the entire column decreased as a direct result of the decrease in surface area of the packing.

Contractor Performance

Total Coliform Log Reduction (TCLR)

During the three-month period between August 2, 1976, to November 2, 1976, a total of 40 experiments were performed with MCWTP effluent to evaluate the total coliform reduction efficiency of the packed column and the jet scrubber. The data were grouped into three segments according to the magnitude of the applied ozone dosage (i.e., low, moderate, and high).

It is clear that the total coliform reduction efficiency in the packed column was superior to the jet scrubber at the low, moderate and high dosage level. When considering all dosage levels combined ($n = 40$) TCLR in the packed column was significantly greater than that in the jet scrubber.

Fecal Coliform Reduction

The fecal coliform data reflect the same trends as the total coliform data. Thus, the packed column out performed the jet scrubber with respect to fecal coliform reduction at low intermediate and high dosage level. When considering all dosage levels, the packed column was significantly better than the jet scrubber with respect to FCLR.

Data from this study conclusively demonstrated a marked difference in performance between two generic type ozone contactors, the packed column and the jet scrubber.

The packed column was superior to the jet scrubber with respect to percent ozone utilization, mass transfer of ozone, and disinfection. This superiority was significant and consistent at all dosage levels employed. The next step in the program is to compare the performance of the packed column with a pressure injector system. This evaluation is now underway and will be followed by diffusers and a turbine agitated contactor. □

Chemical Characterization

Parameter	Mean (mg/l)	Standard Deviation	Range
Temperature ($^{\circ}C$)	21	3	14-24
TCOD	30	10	18-56
SCOD	24	9	15-49
TOC	10.3	5.2	4.4-25.5
TSS	6.7	3.8	2.4-20
TURB (JTU)	3.8	1.5	2.3-7.6
TKN	8.3	8.2	1.9-37.8
NH_3-N	7.2	7.6	0.1-34
ORG-N	1.6	1.0	0.2-3.8
Log Total Coliform Density	5.77	0.51	4.90-6.73
Log Fecal Coliform Density	5.38	0.64	4.36-6.54
Log Fecal Streptococci Density	4.19	0.71	2.70-5.23

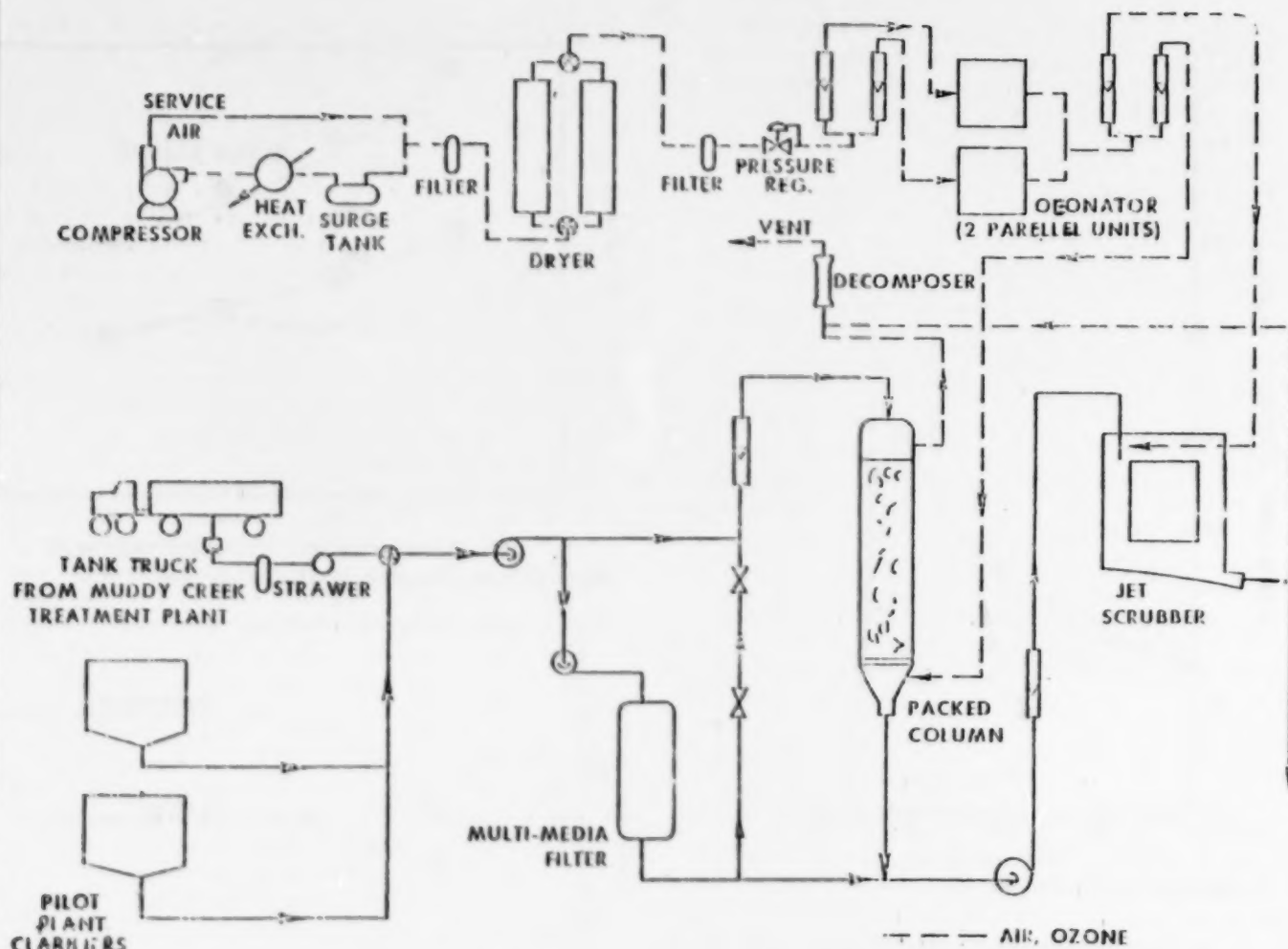


Table I
Effect of Packing Size on Overall Mass Transfer Coefficients (KgVa) of the Packed Column at Various Gas Flow Rates

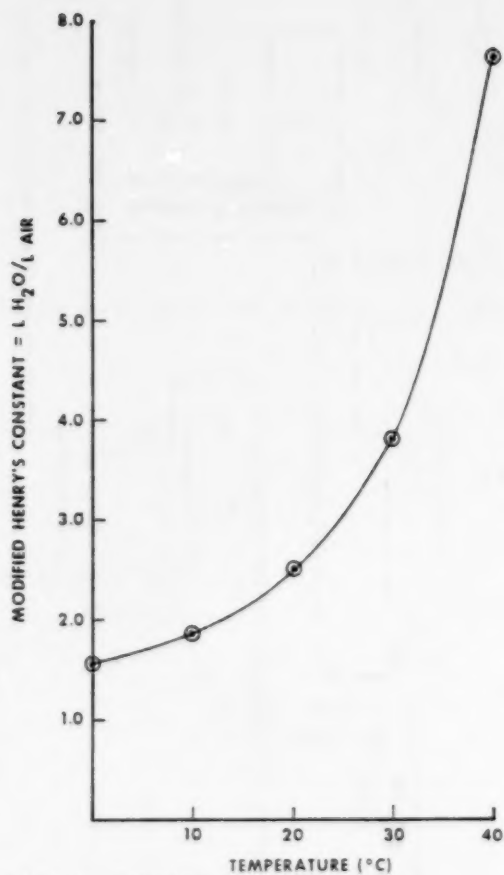
Gas Flow Rate g/min	KgVa (l/min)	
	13 mm Packing (KgV, l/min/m)	25 mm Packing (KgV, l/min/m)
37	84 (0.135)	46 (0.180)
74	163 (0.261)	66 (0.258)
110	175 (0.280)	73 (0.285)
147	205 (0.329)	86 (0.336)

Difference in Total Coliform Log Reduction

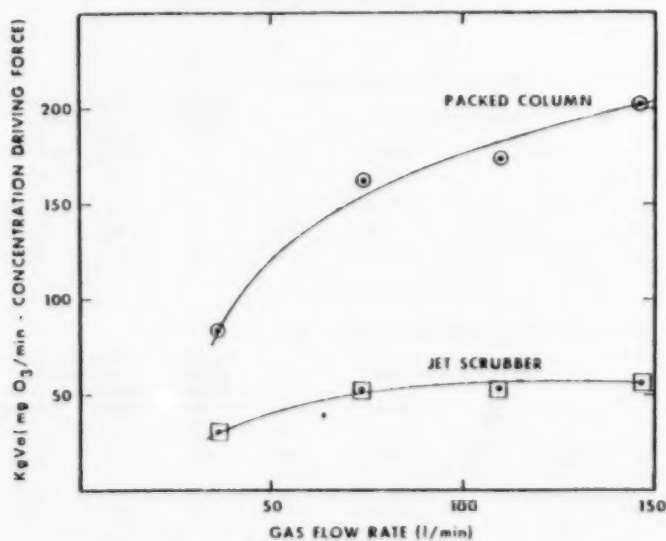
Level	Ozone Dosage (mg/l)		Number of Data Points (n)	Total Coliform Log Reduction	
	Range	Mean		Packed Column	Jet Scrubber
Low	2.4-4.6	3.6	14	2.0	1.4
Intermediate	5.9-10.0	7.5	18	2.8	2.3
High	11.8-18.6	13.9	8	2.4	2.2
All	2.4-18.6	7.4	40	2.4	1.9

Difference in Fecal Coliform Log Reduction

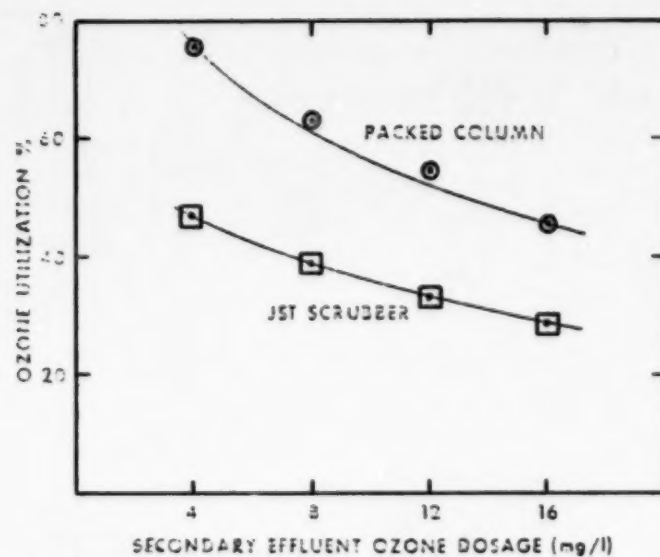
Level	Ozone Dosage (mg/l)		Number of Data Points (n)	Fecal Coliform Log Reduction	
	Range	Mean		Packed Column	Jet Scrubber
Low	2.6-4.6	3.6	13	2.3	1.4
Intermediate	5.9-10.0	7.5	17	3.3	2.8
High	11.8-18.6	14.0	8	3.1	2.5
All	2.6-18.6	7.5	38	2.9	2.3



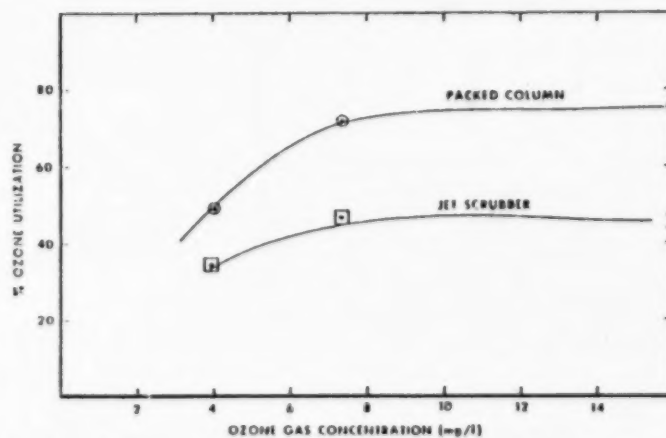
Variation of H With Temperature



Effect of Gas Flow on Mass Transfer Coefficient



Effect of Ozone Dosage on % Ozone Utilization



Effect of Ozone Concentration on Ozone Utilization at Constant Dosage of 8 mg/l

Combined Treatment of Industrial and Municipal Sewages

N. V. Pisanko

At the present time the basic trends in the field of the efficient use of water resources are as follows:

- creation of the closed water supply cycles with the treated sewage reuse;
- introduction of the waterless technological processes;
- improvement of the existing treatment structures and construction of the new modern ones;
- complete sewage treatment with the use of the sorbitioning materials, desalting and ozonizing plants;
- introduction of the local systems of sewage treatment with the extraction of valuable components and treated water reuse;
- sewage sediment treatment and utilization.

In this respect our Institute develops the experimental and standard projects of various structures and plants for water supply and sewerage of many fields of industry.

Selection of optimum variants of water management schemes, considering the technological processes is carried out on electronic computers.

In practice of the industrial water supply and sewerage the technical solutions, developed by the Institute, on the combined treatment of industrial and municipal sewages have been realized, and a number of complex programs for the selection of optimal variants of treatment structures by electronic computers have been devised.

Treatment of Industrial-Complex Sewages Together With Municipal Effluents

One of the promising solutions of the efficient use of water resources is the broad introduction of recycle water supply with the post-treated sewage recharge. Such a project has been carried out by our Institute at the undertaking of the chemical type

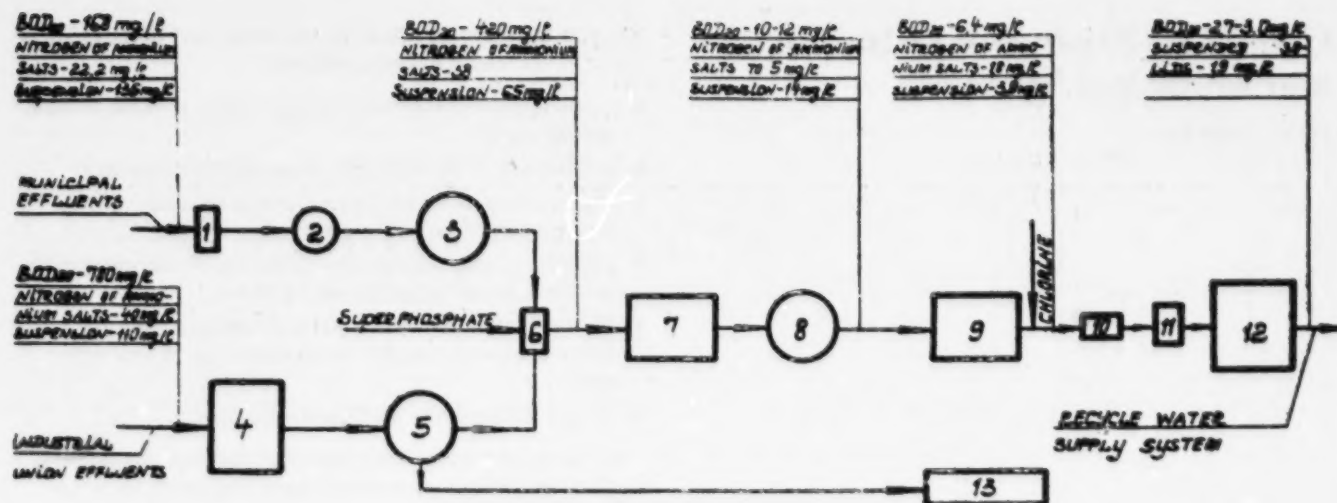
Treatment structures capacity is - 95.0 th.cu.m/day, including: industrial effluents (28.0 th.cu.m/day) and industrial-domestic town's effluents (67.0 th.cu.m/day).

Industrial effluents and domestic effluents of the town flow to the treatment structures' site through the independant sewers and the separate mechanical treatment takes place (see diagram N1). Value of BOD_2 in industrial effluents constitutes 780 mg/l, suspension content - 110 mg/l, nitrogen of ammonium salts - 40 mg/l.

Towns' effluents are characterized by $BOD_2 = 168$ mg/l suspension content - 135 mg/l and nitrogen of ammonium salts - 40 mg/l.

Industrial-domestic effluents after the mechanized gratings (1.) grit chambers (2.) primary settlers (3) (vertical - 9.0 m dia, 8 pcs and radial - 20m dia, 4 pcs) are directed to the mixer (6.)

Industrial effluents after the surge tanks 4(6000 cu.m. and 1680 cu.m capacities), primary settlers 5(vertical - 9.0 m dia, 4 pcs and radial - 20m dia, 3 pcs) are directed to the same mixer 6. Due to the lack of phosphorus in mixed sewages, it is added as a superphosphate solution to the mixer from the building for chemicals.



1-GRATINGS; 2-GRIT CHAMBERS; 3-PRIMARY SETTLERS OF MUNICIPAL EFFLUENTS; 4-SURGE TANK; 5-PRIMARY SETTLERS OF INDUSTRIAL EFFLUENTS; 6-MIXER; 7-AERATION TANK-MIXER; 8-SECONDARY SETTLERS; 9-BIOLOGICAL PONDS; 10-CONTACT TANK; 11-TRANSFER PUMPING STATION; 12-FILTRATION STATION; 13-SLUDGE COLLECTING POND

Diagram 1
Treatment of Industrial Union Sewage Combined with Municipal Effluents.

After mixing the effluents have the following characteristics: BOD_{20} —420 mg/l; suspension content—65 mg/l, nitrogen of ammonium salts—38 mg/l. Effluents mixture is treated at the biological treatment structure, comprising the aeration tanks—mixers 7 (24 and 44 th.cu.m capacities) and secondary radial settlers 8 (20 m dia—12 pcs).

Effluents aeration in aero-tanks is pneumatic, residence time—22 hours. Aero-tank acidic power by BPK_{20} is accepted as 22.0 g/cu.m/h.

After biological treatment, water with BOD_{20} —10–12 mg/l, suspension content—14.0 mg/l, nitrogen of ammonium salts—5.0 mg/l flows for post-treatment to biological ponds 9 of 260 th.cu.m capacity. After post-treatment in biological ponds (during 3 days) effluents possess the following data:

BOD_{20} —6.4 mg/l, suspension content—3.9 mg/l, nitrogen of ammonium salts—1.8 mg/l, dissolved oxygen—8.0 mg/l.

After biological ponds sewages are disinfected with chlorine in the contact tank 10 and pumped by the pumping station 11 to the filtration station 12, consisting of horizontal settlers and sand filters. Before going to settlers water is treated with coagulants. Water, treated at filtration station, with BOD_{20} —2.7–3.0 mg/l and suspended solids content—1.6–1.9 mg/l is supplied for the recycles recharge. Sediment from primary settlers 5 of industrial effluents is pumped over into the slime collecting pond of 425 th.cu.m capacity. Sediment from primary settlers of municipal effluents is mixed with excessive activated sludge, passed through the sludge compactors, and is fed to methan tank, where it is fermented in mesophylic conditions (at temperature to +35° C).

Fermentated sediment is directed to sludge areas with asphalt-concrete base. Because of the toxic substances in sediment its use was not possible and after drying it was directed to storage places.

Selection of Optimum Variant of Sewage Post-Treatment Structures By Electronic Computers

From the practice of treatment structures operation it is obvious that, very often, to provide the normative sanitary-hygienic indices of the reservoir (in the rated range) the sewage post-treatment is to be provided.

In some cases for post-treatment structures the large plots of land are required (biological ponds with natural aeration) but no electric power is needed. In other cases—small area and considerable electric power consumption (aerated biological ponds, filters flotators) are required. So, when choosing the optimum variant of effluents post-treatment the great and labor-consuming work (which is some cases is not possible to be performed by familiar methods of calculations) is to be done.

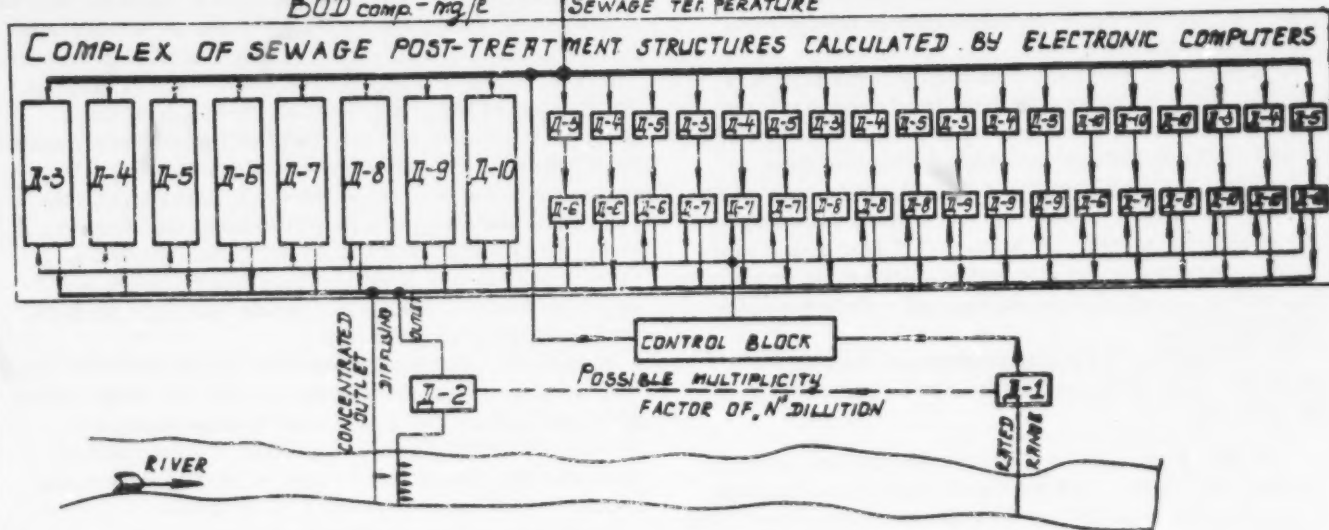
The complex program of the selection of the optimal variants of sewage post-treatment by the electronic computers is developed by the Institute.

As a basis for the program (see diagram 2) the following structures tested in practice and providing the sufficient sewage post-treatment degree as to the single-stage diagram are accepted:

- 1) Biological ponds with natural aeration (D-3);
- 2) Biological ponds with mechanical aeration (D-4);
- 3) Biological ponds with weirs-aerators (D-5);
- 4) Rotary gratings, granular filters, aeration devices (D-6);
- 5) Strainers and aerated filters (D-7);
- 6) Rotary gratings, granular filters with chemicals treatment (D-8);
- 7) Strainers (D-9);
- 8) Flotators (D-10);

STRUCTURES OF COMPLETE BIOLOGICAL TREATMENT

FLOW RATE Q - l^3 cu.m/day Q_2 - mg/l. HARMFUL SUBSTANCES
BOD comp. - mg/l. SEWAGE TEMPERATURE



D-3 - BIOLOGICAL PONDS WITH NATURAL AERATION; **D-4** - BIOLOGICAL PONDS WITH MECHANICAL AERATION;
D-5 - BIOLOGICAL PONDS WITH WEIR; **D-6** - FILTERS; **D-7** - REVERSED FILTERS **D-8** - FILTERS WITH
CHEMICAL TREATMENT; **D-9** - STRAINERS; **D-10** - FLOTATORS.

Diagram 2
Selection of Optimal Variant of Sewage Post-Treatment Structures.

Various combinations of above single-stage diagrams of the sewage post-treatment structures made it possible to develop 18 dual-stage diagrams, providing more complete post-treatment, than single-stage system, and to get minimum structures cost by means of correct-distribution of the pollutants removal degree separately for each stage.

To calculate the sewage mixing with reservoir water the following programs are developed: D-1 (concentrated outlet) and D-2 (diffusing outlet).

By the program D-1, the calculation of which is related to the sewage inlet reservoir and its rated range, the values of limiting-allowable concentrations of pollutants (to be discharged into the given reservoir) by BOD_{comp.}, suspended solids and harmful substances, and temperature are determined.

Limiting-allowable concentrations, which do not disturb the physical-chemical composition of the reservoir are to be provided in the rated range.

Data, developed by the program D-1, are the final parameters of all variants of sewage post-treatment structures considered. These data are transferred to all variants of structures.

Calculation of the diffusing outlet is performed by the program D-2. This calculation takes place to examine the possibilities of replacing the post-treatment structures by the diffusing outlet and to remove, if necessary, the partial load on post-treatment structures as well.

All variants of sewage post-treatment structures (single and dual stages) are calculated in 2 combinations: a) with

concentrated outlet; b) with diffusing outlet.

Calculation of each variant is carried out in the following order:

A) All technological parameters of sewage post-treatment structures are calculated:

—ponds areas, the number of mechanical aerators, weir-aerators for any climatic region of the country, considering the temperature drop factor;

—filtration rate, filters area, filters type;

—flotation time, flotators number, power capacities.

Calculation culminates in the determination of all parameters of structures in all operating conditions.

B) Estimate-economical parameters are determined from the technological ones.

As a criterion of optimum factor the reported costs are accepted.

Capital costs are dependent on the capacity and sizes of structures and are estimated from the predetermined graphical relationship, converted to mathematical language.

Based upon the operating efficiency of complete biological treatment structures, the following values of pollutants concentrations, entering the post-treatment structures are accepted; by BOD_{comp.} - 15, by suspension - 15 mg/l. by dissolved oxygen - 0.5 - 2.0 mg/l. Sewage temperature ranges from - 6 to - 30° C.

On the basis of data on residual concentrations of pollutants after the complete biological treatment as well as on harmful

substances when discharging into the reservoir and determined from the calculation program on mixing (D-1; D-2) it was by the following:

- a) ability of the post-treatment structures to remove pollutants, considering the partial load on the reservoir and BOD in the rated range.
- b) ability of the river itself to reduce the concentration of discharged harmful substances in the rated range due to the stream turbulence up to the limiting-allowable concentrations.

After the post-treatment structures the value of these pollutants, according to programs $D_3 \div D_4$ will be reduced up to 5 mg/l (by BOD_{comp}) and – up to 4 mg/l (by suspension); according to the program D_7 this value will drop up to 3 mg/l (both by BOD and suspension) and according to the program D_9 it will be up to 11 mg/l (by BOD_{20}) and – up to 6 mg/l (by suspension).

The introduction of complex programs of choosing the optimum variant of sewage post-treatment structures provides the following:

1. To determine in the shortest time the optimum variant of sewage post-treatment considering the sanitary and hydraulic condition of the reservoir over the capacities range from 0.5 up to 5000 th.cu.m/day.
2. To get the sizes of all structures, comprising communications between structures, on each variant.
3. To determine the allowable pollutants concentrations before biological treatment structures.

Application of Aeration Tanks-Clarifiers for Biological Sewage Treatment

An aeration tank clarifier developed by our Institute is one of the efficient structures, which will find wide application at biological treatment stations. This structure is used for combined treatment of sewage from metallurgical undertakings in a town.

After mixing the sewage at the rate of 50 th.cu.m/day are characterised by $BOD_{20}=110$ mg/l and suspension content =95mg/l.

After mechanical treatment (gratings, grit chambers and primary settlers) sewages are directed to biological treatment, which is realized in aeration tanks-clarifiers. An aeration-tank-clarifier measures 48.0×20.0 m, its capacity – 10.0 th.cu.m/day, and with forced operating conditions it accounts for 15.0 th.cu.m/day.

Aeration tanks-clarifiers are prefabricated-monolithic structures, their design-flow diagram is presented in fig. 1.

An aeration tank-clarifier operates in the following way. Sewage is fed through the delivering pipe dispersely along the length of the structure to the aerations zone 2, where it is mixed with air and circulating activated sludge. Air supply is performed from the air-blowing station through the air pipes (3) to channels with plate diffusers (4) and tubular aerators (10.)

Aerated sludge mixture through the holes in partitions (5.) controlled with gate valves enters the clarification zone (8.) meanwhile passing the stream baffling zone (4.) where the separation of suspended air bubbles takes place as well. Zone of stream pulse baffling is separated from the clarification zone

by the partition (14.) Further the stream runs along partitions (13.) then enlarging it breaks down into parts. One part of the stream goes upwards in the direction of the diverting trough. It acts as a motive force for the formation of a suspended layer of activated sludge 8, where organic pollutants are detained and oxydized. Due to the enlargement of the stream, its movement rate reduces, which is beneficial for better water clarification. Another part of the stream flows downwards along the partition. It acts as a motive force when forming the permanent recirculation between aeration and clarification zones. The circulation is also provided by the slot 8, through which the stream is drained to aeration zone caused by the intensive rising of air bubbles, produced by fine-bubble aeration 4.

In order to prevent clogging of recirculating channels, the tubular aerators 10 of perforated pipings with 5mm dia holes are provided in their lower part.

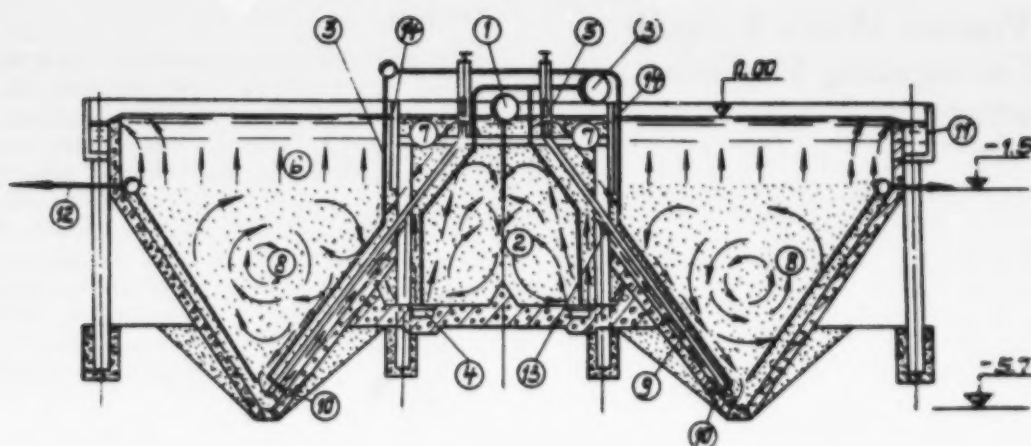
Wastewater, treated from pollutants and filtered in the sludge suspended layer is removed uniformly from the whole surface of the clarification zone by the water diverting troughs 11. Between the suspended layer 8 and a level of the clarified water overflow, the protective layer of clarified liquid 6, the height of which varies from 1 to 1.5m, is formed.

Excessive activated sludge under hydrostatic pressure is diverted through the piping 12 of 150mm diameter for the following treatment. Operating experience of the existing aeration tanks-clarifiers demonstrated, that with the sewage treatment for 5 hours, pollutants concentration reduces to 8–9 mg/l, suspension content – to 7–11 mg/l.

Aeration tank-clarifier differs from the known biological treatment structures mainly by the hydrodynamic improvement of the structure design itself, which promoted the formation of the steady suspended layer of activated sludge in clarification zone and its higher buffer ability, provided an intensive mass exchange between the aeration and clarification zones and complete and rather intensive mixing inside the layer at a time. An intensive exchange between the mass of activated sludge in the suspended layer and aeration zone made it possible to provide an activated biomass in the suspended layer with oxygen and feed, uniformly with time and layer volume. The combination of aeration and settling zones allowed for producing the optimal conditions of vital activity of activated sludge organisms. The activated sludge is always to be found in aerobic conditions, as the flow rate of circulating streams is superior to the flow rate of treated water 7–15 fold. The peculiar form of aerated zone aids in rising the turbulence of sewage liquid stream and, thus, in the intensification of the process of oxygen mixing and dissolution.

Due to the filtrational mixing of the mixture in the mass of the suspended layer, the conditions of phases, contacting between themselves are improved, the oxydizing rate therewith increases 1.8–2 fold as opposed to "traditional" aeration tanks.

The intensity of the exchange between the aeration and clarification zones is high to such an extent, that a structure as a whole is practically a reactor-mixer, in which the process is accomplished in full volume, occupied by activated sludge, and the whole reserve of the active biomass is involved in oxidizing process at a time.



1-WATER DELIVERING PIPE; 2-AERATION ZONE; 3-AIR-PIPES; 4-CHANNELS WITH PLATE DIFFUSERS; 5-HOLES IN PARTITIONS; 6-CLARIFICATION ZONE; 7-STREAM BAFFLING ZONE; 8-SUSPENDED LAYER OF ACTIVATED SLUDGE; 9-SLUDGE RECIRCULATION SLOT; 10-TUBULAR AERATORS; 11-WATER DIVERTING; 12-EXCESSIVE SLUDGE PIPING; 13, 14-PARTITIONS.

Figure 1.
Aeration Tank-Clarifier.

The sludge mixture flowing from aeration zone to the clarification zone is separated in suspended layer by filtering. Efficiency of separation of such a dispersed phase by filtering is much higher than by settling; so the total effect of sewage treatment in aeration tank-clarifiers is higher than in complexes of aeration tanks with secondary settlers and in aeration tank-settlers.

The suspended layer of activated sludge in clarification zones is characterised by the high stability due to the fact that the suspending factor in this case is not the sewage stream, but a circulating stream getting energy from the aeration system, which is smoothly controlled. This aeration system provides the drop of hydrostatic pressures between the aeration and clarification zones. The application of aeration tanks clarifiers makes it possible:

- to give up the construction and operation of individually standing secondary settlers as well as a system of pipings and pumping units for pumping over the circulating activated sludge;
- to increase the capacity of the biological treatment structures 2-fold in the same aeration tanks volumes and in the same areas;
- to decrease the air and electric energy consumption two-fold.

When comparing the variants of sewage biological treatment in aeration tanks-clarifiers and in aeration-tanks with secondary settlers it was found, that in the first case the area to be built drops from 4266 to 2880 sq.m, electric power—from 63.0 to 37.3 th.roubles/year.

Concentration of organic matter in industrial sewages often exceeds 1 g/l, which is considerably much higher than in domestic effluents.

Usually in industrial effluents the biogen elements are not available: phosphorus and nitrogen, which are present in domestic effluents. So the combined treatment of domestic and industrial effluents, as a rule, is more efficient, than the treatment of industrial effluents themselves.

It is not unusual to find that only by way of combined treatment of industrial and domestic sewages the required degree of their treatment can be obtained.

The rapid industry and town development results in the necessity of solving the more complicated problems in the field of industrial and domestic sewages treatment.

Therefore the conducting of this symposium, where we have the opportunity for the experience exchange, will promote further progress in the field of sewage treatment and environment protection. □

Closed Process Water Loop in NSSC Corrugating Medium Manufacture

John W. Collins
EPA

Abstract

A 3000/day corrugating medium plant found that their machine process water could be reused extensively reducing their effluent BOD₅ and suspended solids to acceptable levels. Machine process water was reused on showers, dilution of stock entering the centrifugal cleaners, before the refiners and at the screw press and in the digester. Volume surges were controlled by a reverse osmosis unit capable of handling 28,000 gal/day. Problems with life of the modules and fouling of the membranes are discussed briefly. Product yield increased some 5-6% with dissolved solids showing little effect on the paper board's acceptability. Costs for the reverse osmosis are compared with double effect and vapor compression evaporation.

Introduction

The preferred method of waste water treatment is to eliminate the effluents by altering the manufacturing processes. Several pulp and paper mills have been successful in doing this. One of particular interest is an NSSC (neutral sulfite semichemical) mill in Green Bay, Wisconsin. Working with the Institute of Paper Chemistry and the Environmental Protection Agency, the Green Bay Packaging Company has converted its operation from one requiring extensive end-of-pipe treatment to one requiring no effluent treatment. The mill produces a corrugating medium from a mixture of mixed hardwood NSSC pulp and recycled corrugated box plant waste fiber. Most of the solids pulped from the wood are burned in a fluidized bed to recover sodium sulfate which is sold to a kraft mill. The residual pulping liquor organics (approximately 25%) accompany the fibers to the paper machine. By running the white water at a high solids concentration, the remaining organics are incorporated in the board. Upsets in the system can create as much as 28,000 gal/day of excess "white water". To process this excess and recover the solids for recycling a reverse osmosis unit is used. This report will review some of the process changes and the adaptation of reverse osmosis to the system.

Recycle System

A balanced operation of the final system is diagramed in Figure 1. The machine "white water" or process water is reused on machine showers for dilution of stock to the centrifugal cleaners, in the repulper and in dilution after the screw press, at the screw press and in the digester. Clarification of the process water for fourdrinier shower is now shown here. Various storage tanks are not shown either.

Clarified white water and reverse osmosis concentrate 4-6% dissolved solids are reused in the pulp mill eventually going to the evaporators. The arrangement of the units are shown in Figure 2. Evaporator condensate, cooling water, vacuum seal water and reverse osmosis permeate make up the mills final effluent which was reduced from 1.8 to 1.6 M²GD.

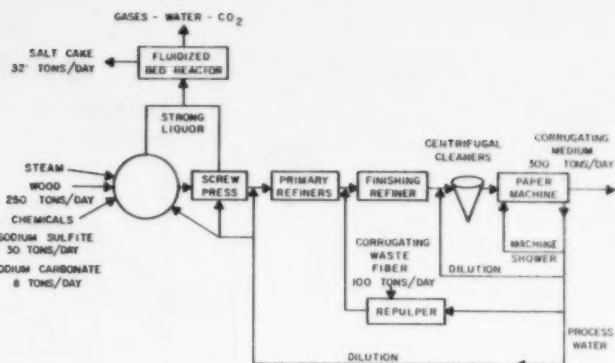


Figure 1.
Mill process.

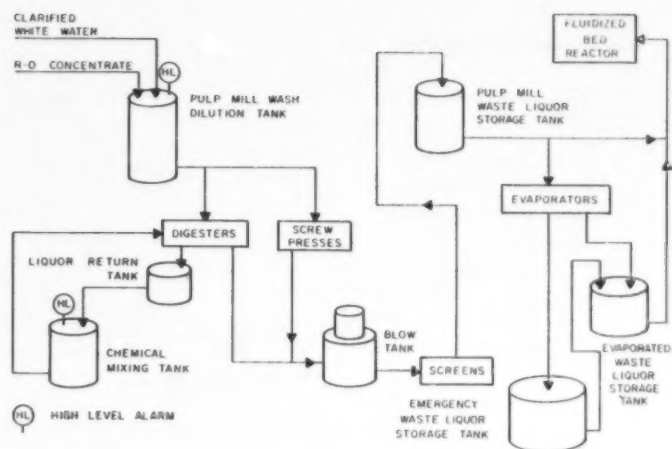


Figure 2.
Pulp mill—combustion plant liquor flow.

Effect of Mill Closure on Pollution Load from the Mill

Following strong liquor combustion, but, prior to the water reuse program, the BOD₅ averaged around 20,000 lbs/24 hrs. Figure 3 shows the reduction of BOD₅ in the effluent as the program progressed. Currently some 1.6 M³/GD of effluent are discharged with around 1,000 lbs of BOD₅/day. Two Figures, 4 and 5 compare the pollutants before and after the water reuse program. BOD₅ was reduced from 6,000 lbs/day to 1,000 lbs/day, suspended solids from 1,122 to 420 lbs/day. Further reductions would require treatment of vacuum seal waters and felt washings. If reverse osmosis were to accommodate the plant volume would have to be four times the size. Figure 5 shows the condition of the River water. The discharge quality is fairly close to the Fox river water. As the river water improves, the mills discharge will improve.

Reverse Osmosis

Reverse osmosis is a concentrating process based on the permeability of a membrane to water but not the dissolved solutes. Pressurizing the solution to be concentrated against the membrane provides the work required to overcome the osmotic

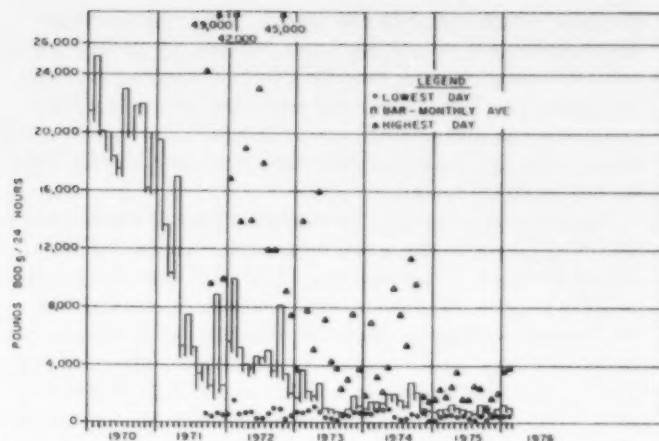


Figure 3.
Historical mill discharge performance.

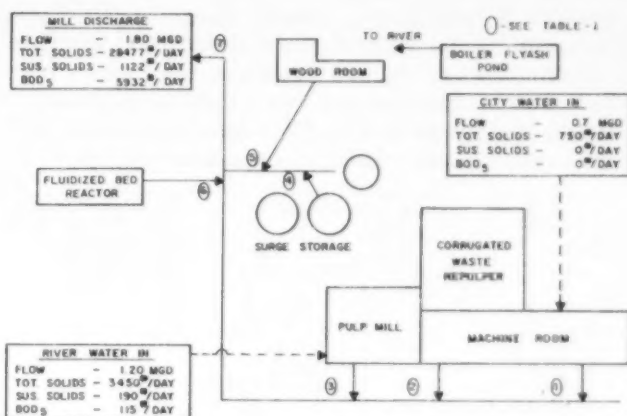


Figure 4.
Mill discharge stream—1971.

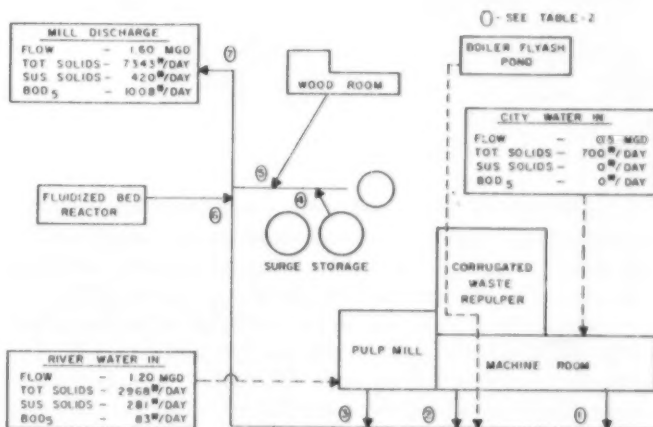


Figure 5.
Mill discharge stream—1975.

pressure. Assymetric cellulose acetate membranes were the first found to give reasonable water flux and are preferred after some 15 years following their discovery. Preliminary trials at the Institute of Paper Chemistry and at the Green Bay Mill resulted in the selection of a spun Fibreglas $\frac{1}{2}$ in diameter tube lined on the inside with the thin membrane now manufactured by Universal Oil Products.

The unit was situated in the overall scheme of water reuse as shown in Figure 6. The actual setup of the 18 tube modules is shown in Figure 7. Not shown is a heat exchanger to cool the process water or the screens used to clarify the stream. The feed pumps are high pressure centrifugal pumps with 47 stages for pressurizing and 23 stages for recirculation. The plant can process up to 28,000 gal/day at a flux rate of 5 gfd (gal/sq ft per day). To control fouling of the membrane surface, considerable effort was directed toward working out the most efficient cleaning schedule. Currently the system operates with periodic automatic pressure releases to allow some of the permeate to repenetrate the membrane by osmosis, thereby, removing some of the solids from the inner membrane surface. This shutdown is carried out every 2 hours for 12 minutes. Once a day a high velocity flush is carried out and once a month an enzymatic detergent cleaning and soak for 12-18 hours is carried out to remove chemical scale which is mostly calcium oxalate.

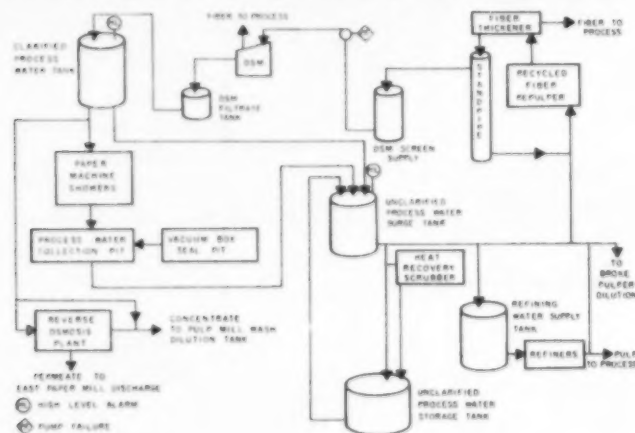


Figure 6.
Process water reuse system.

Problems with the reverse osmosis equipment were also experienced. The first set of support tubes were subject to premature bursting. The Fibreglas support structure weakened during the 600 psi operation. A careful examination of the manufacturing process and the raw materials before and after exposure to this 5% solids NSSC machine process water revealed permeate etching of the Fibreglas strands. Certain trace components were being leached out rendering glass weakened and subject to fracture. Changing the composition of the glass led to a new generation of modules. The life has been extended from some 1,000 hours to 12,000 hours.

With so many operating variables, the system needs a number of controls. Figure 8 shows the various control devices used to protect the membranes and ensure a continuous smooth operation.

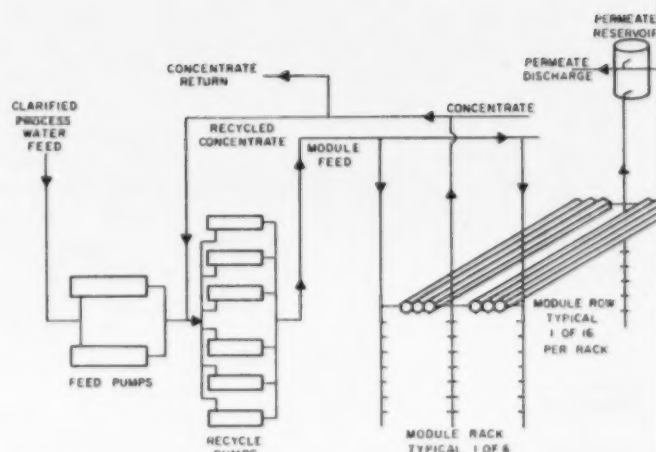


Figure 7.
Reverse osmosis flow diagram.

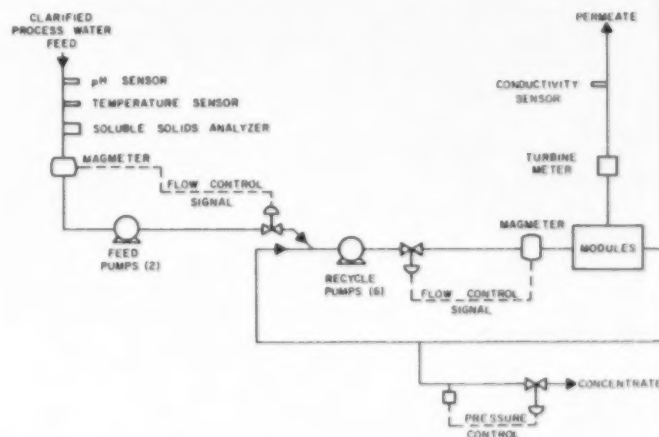


Figure 8.
Reverse osmosis plant control.

Product Quality

Table 1 shows the properties of the paper before and after the water reuse measures. A drop in mullen was the only significant change. Acceptance by the processors and consumer did not change. Costs are summarized in Table 2. The reverse osmosis processing is less expensive to operate than the two effect evaporator but not the vapor compression evaporator. Capital installed costs were most for the reverse osmosis equipment. This relatively high cost is partly due to the small size of the plant, the elaborate control required and the extensive measures to control fouling.

Table 1
Strength Comparison—Open System, 1970, to Closed System, 1975

1. Item	2. Year	1975
3. Paper machine		
4. Basis weight (pounds/1000 sq. ft.)	26.3	26.1
5. Concora (pounds)	71.8	70.6
6. Mullen (pounds)	42.0	34.0
7. Corrugator		
8. Flat crush (pounds/sq. in.)		
9. A Flute	30.8	30.1
10. B Flute	48.1	55.0
11. C Flute	46.5	40.3
12. Standard box, top to bottom compression strength (percent of standard)	100.6	107.4

Table 2
1976 Capital and Installed Costs

1. Total installed cost	2. Reverse Osmosis	3. Two Effect Evaporator	4. Comparable Vapor Compression Evaporator
1. Total installed cost	\$324,572	\$200,000	\$250,000
5. 1974-1975 Operating Cost Experience			
6. Operating cost—\$/3.785 cubic meters (1000 gal.) purified water			
7. Energy consumption	\$ 1.70	\$ 8.60	\$3.34
8. Depreciation	6.45	3.18	3.71
9. Maintenance and labor	2.58	.91	.99
10. Total cost—\$/3.785 m ³	\$10.73	\$12.69	\$8.04

Conclusions

1. A corrugating medium mill using hardwood NSSC pulp and recycled corrugated box plant waste fiber has found it can operate successfully discharging an effluent requiring no treatment to meet current federal and state regulations.
2. Corrugating medium can be produced from a pulp slurry containing process water 160° F and 5% dissolved solids.
3. Corrosion, scale, foam, slime and deposits can be controlled by changes in equipment composition or by conventional techniques.
4. Reverse osmosis can recover solids for the paper machine thereby keeping BOD₅, color and suspended solids from the sewer.
5. The additional dissolved solids (5%) that are incorporated in the sheet have had no significant effect on the paper board's acceptability.

Protocol

Of the Sixth Meeting of the USA and USSR delegations on the problem of Prevention of Wastewater Pollution from Industrial and Municipal Sources (Cincinnati, Ohio, Chicago, Illinois, Washington, D.C., USA, May 7-16, 1978)

In accordance with the Memorandum of the Sixth Meeting of the Joint USA/USSR Commission on Cooperation in the Field of Environmental Protection (Washington, D.C., November 1977), the USSR and USA delegations meeting on the problem of Wastewater Treatment was held May 7-16, 1978.

The Soviet Delegation was headed by Roald F. Slavolyubov, Department Head Central Administration of Gosstroy, USSR.

The American Delegation was headed by Mr. Harold P. Cahill, Jr., Director of the Municipal Construction Division, U.S. Environmental Protection Agency.

The list of participants is attached in Appendix 1.

In the course of the visit, the following was accomplished:

1. A Symposium on the topic of Advanced Equipment and Facilities for Wastewater Treatment was held in Cincinnati.
2. The results of fulfillment of the 1977-1978 Program of Scientific Research Cooperation.
3. Coordination of research projects to be fulfilled in 1978.
4. Consideration of the possibility of the free exchange of the design documentation for the construction of an experimental municipal industrial wastewater treatment facility.

1. In the course of the Symposium, 11 technical papers were delivered: 5 papers from the Soviet side and 6 papers from the U.S. side (Appendix 2).

All papers were received with great interest and were followed by a lively discussion.

The delegations have agreed that each side will publish all papers in the required number of copies in its own language prior to November 1, 1978, and will distribute them among interested organizations. The sides will exchange 10 copies each of the published Proceedings of the Symposium.

2. During the Meeting, the delegation visited industrial and municipal treatment facilities and laboratories in Cincinnati, Ohio; Chicago, Naperville and Dyer, Illinois; and Whiting, Indiana; and Occoquan, Virginia. The technology of wastewater treatment was carried out there with the specialists from the All-Union Scientific Research Institute VODGEO, Soyuz Vodokanalproekt, EPA, Metropolitan Sanitary District of Greater Chicago, and the AMOCO Research Center.

Both sides agreed that the seventh symposium on the following topic will be held in the USSR:

- Facilities for Tertiary Treatment of Biologically Treated Effluents Including Removal of Biogenous Elements (from August 20-September 2, 1978).

In preparation for the forthcoming symposium the following was agreed upon:

- Each side will prepare 5-6 technical papers;
- Both sides will exchange the titles of papers to be delivered six weeks prior to the beginning of the symposium.
- Both sides will exchange the texts of the papers both in Russian and in English one month prior to the symposium.

In 1978 a long term exchange for one month will be carried out. American specialists will visit the Soviet Union in June-July 1978. Soviet specialists will visit the USA in October-November 1978. Expenses related to this exchange of specialists will be carried out on the basis of "receiving-side pays" basis.

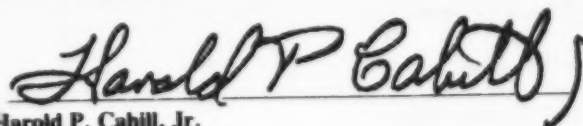
4. The delegations discussed the possibility of an exchange of specialists and technical documentation for the use in construction of an experimental municipal and industrial wastewater and sludge treatment facilities in 1979-1980.

The sides developed and coordinated the working program for 1979, taking into account exchanges carried out in this area by U.S. and Soviet specialists of the paper and pulp, chemical and petroleum industries. Namely: the visit to the U.S. by Soviet paper and pulp specialists in February 1978, the visit to the USSR of American paper and pulp specialists in July 1978, as well as the planned visit to the U.S. by Soviet petroleum industry specialists in October 1978.

The program envisages two meetings of the American and Soviet specialists. The first meeting to take place in the USA in the spring of 1979. During that meeting, the sides will review the nonreimbursable projects recommended for the experimental treatment facilities. At that time, a symposium will be held on the treatment of oil refinery wastewaters and a summary of experience on closed oxytank performance. The second meeting will take place in the USSR in the summer of 1979. At this meeting, projects of advanced municipal and industrial wastewater treatment technology recommended by both sides, shall be presented and the facilities to be constructed for experimental projects shall be determined.

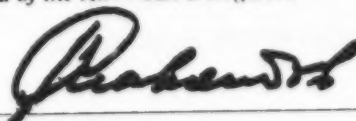
The sides expressed satisfaction that the present meeting was held on the high scientific-technical level in the atmosphere of friendship and mutual understanding and contributed to the further strengthening and development of the cooperation in the field of the environmental protection.

The record of the proceedings of the meeting is signed on the 16th of May 1978 in two copies in the English and in the Russian languages, both texts are equally authentic.



Harold P. Cahill, Jr.

Head of the American Delegation



R. F. Slavolubov

Head of the Soviet Delegation

Appendix 1

List of Participants at the Symposium "Advanced Equipment and Facilities for Wastewater Treatment"

From the American Side:

Harold P. Cahill, Jr.

Delegation Leader

Director, Municipal Construction Division, US EPA

John T. Rhett

Deputy Assistant Administrator for Water Program Operations,
US EPA

William J. Lacy

Deputy Leader of Delegation

Principal Engineering Science Advisor, Office of Research and
Development, US EPA

R. John Garner

Director, Health Effects Research Laboratory, Office R&D,
US EPA, Cincinnati, Ohio

Francis T. Mayo

Director, Municipal Environmental Research Laboratory, US
EPA, Cincinnati, Ohio

Frank P. Sebastian

Senior Vice President, ENVIROTECH, Menlo Park,
California, USA

John W. Collins

Senior Scientist, US EPA, Cincinnati, Ohio

James Westrick

Senior Scientist, US EPA, Cincinnati, Ohio

John N. English

Senior Scientists, US EPA, Cincinnati, Ohio

Edward J. Opatken

Senior Scientist, US EPA, Cincinnati, Ohio

U. V. Henderson

Senior Researcher, Texaco, Inc., Port Arthur, Texas, USA

Prof. Alexey N. Malyshev

Interpreter, US Department of State

From the Soviet Side:

Roald F. Slavolyubov

Delegation Leader, Department Chief of Main Administration,
USSR State Committee on Building Construction, USSR

Aleksey N. Belevtsev

Senior Researcher, All-Union Research Institute of Water
Supply, Sewage, Hydrotechnical Construction and Engineering
Hydrogeology, VNII VODGEO, USSR

Khafiz K. Karimov

Manager, Tashkent Department of Water Economy of Industry
and Populated Areas, All-Union Research Institute of Water
Supply, Sewage, Hydrotechnical Construction and Engineering
Hydrogeology, VNII VODGEO, USSR

Kseniya M. Morozova

Senior Researcher, All-Union Research Institute of Water
Supply, Sewage, Hydrotechnical Construction and Engineering
Hydrogeology, VNII VODGEO, USSR

Nikolay V. Pisanko

Chief Engineer, State Project Institute, "Ukrvodokanal
Project," USSR State Committee on Building Construction

Appendix 2

List of Papers Presented at the Symposium, "Advanced Equipment and Facilities for Wastewater Treatment"

From the American Side:

Removal of Volatile Halogenated Organic Compounds by Activated Carbon

James Westrick

Activated Sludge Enhancement: A Viable Alternative to Tertiary Carbon and Absorption

U. V. Henderson

Wastewater Treatment for Reuse and Its Contribution to Water Supplies

John N. English, Howard P. Warner, Irwin J. Kugelman

Training for Use of Advanced Wastewater Treatment Equipment and Facilities

Frank Sebastian

Contractor Design for Ozonation of Wastewater

Edward J. Opatken

Closed Process Water Loop in NSSC Corrugating Medium Manufacturer

John W. Collins

From the Soviet Side:

Intensification of Mechanical Methods of Cleaning Wastewater in Oil Refineries

I. N. Myasnikov, L. V. Gandulina, K. K. Karimov

Electrochemical Methods of Cleaning Wastewater

A. N. Belevtsev

Cleaning Wastewater in Lacquer and Paint Production

I. N. Myasnikov, N. Y. Vorobyeva, L. V. Gandulina, Y. V.

Kedrov

Construction to Facilities for Separating Sludge Mixture in Biological Cleaning of Wastewater in the Chemical Industry

I. V. Skirdov, S. I. Kolletsova, K. M. Morozova

Joint Cleaning of Mixed Industrial and Municipal Wastewater

N. V. Pisanko

Appendix 3

USA-USSR Cooperation of Working Group on Prevention of Water Pollution from Industrial and Municipal Sources for 1979

TITLES	FORM OF WORK	RESPONSIBLE FOR		TIME	EXPECTED RESULTS
		From the USSR	From the USA		
Modernization of existing and development of new combined facilities with high efficiency for wastewater treatment, including hydrocyclones, multistage settlers, flotators, facilities with utilization of technical oxygen, investigation of usage of flocculants and coagulants.	Joint development of themes, scientific information and specialists delegation exchange. Symposium on: "Treatment of Wastewater Containing Oil" (USA, April 1979)	VNII VODGEO Gostroy USSR	EPA	1979	Improvement of the efficiency of existing and development of new treatment facilities, reduction of reagents and cost of wastewater treatment.
Development of hydrocyclones and pressure flotation units.		VNII CODGEO Gostroy USSR		1980	Recommendations for designing hydrocyclones and pressure flotation units.
Development of tubular and plate settlers.			EPA	1980	Recommendations for use of settlers for wastewater treatment.
Development of open aeration tanks of "Marox" type with the usage of technical oxygen.			EPA	1980	Development of open aeration tank with the usage of technical oxygen.
Development of closed combined aeration tanks of "Oxitan" type with the usage of technical oxygen.	Information and delegation exchange		EPA	1979	Development of closed aeration tanks with the usage of technical oxygen.
Development of multi-media filters with gradually descending particle size distribution		VNII CODGEO		1979	Recommendations for designing filters for treatment and final treatment of wastewaters.
Development of multi-media filters and facilities with continuous washing.		EPA	1979		Recommendations for construction of multi-media filters.
Intensification of wastewater treatment processes in petrochemical, chemical, petroleum refining and pulp and paper industries.		VNII VODGEO	EPA	1979	Increasing of wastewater treatment efficiency of existing treatment plants, introduction of new treatment schemes, maximum usage of treated effluents in recirculating systems.
Intensification of wastewater treatment processes in petroleum refining industry.	Joint development of themes, information and delegations exchange.	VNII VODGEO		1979	Development of treatment scheme of a petroleum refining plant using mechanical, physical, chemical and biochemical methods.
Intensification of wastewater treatment processes in petrochemical and pulp and paper industries.			EPA	1979	Development of treatment scheme of pulp and paper petrochemical enterprises using reagents.
Development of highly efficient methods and facilities for municipal sewage treatment with removal of biogenous elements; usage of treated effluents in recycling systems at industrial enterprises.		VNII VODGEO	EPA	1980	Development of new treatment facilities for prevention of water basing eutrophication; development of new treatment systems with maximum usage of treated effluents in recycling systems at industrial enterprises.
Development of methods and facilities for nitrates and nitrites removal.					

Appendix 4

Program Joint US/USSR Symposium May 9-10, 1978

Tuesday, May 9

8:30 a.m. Registration
9:00 a.m. Opening Remarks—John T. Rhett
9:15 a.m. Welcome—Dr. R. John Garner
9:30 a.m. Removal of Volatile Halogenated Organic Compounds
by Activated Carbon—James Westrick, EPA,
Cincinnati, Ohio
10:15 a.m. Break
10:30 a.m. Intensification of Mechanical Methods of Cleaning
Wastewater in Oil Refineries—I.N. Myasnikov, L.V.
Gandulina, K.K. Karimov, USSR
11:15 a.m. Activated Sludge Enhancement: A Viable Alternative
to Tertiary Carbon and Absorption—U.V. Henderson,
Texaco, Inc., Port Arthur, Texas
12:00 Noon Discussion
12:15 p.m. Lunch
1:30 p.m. Electrochemical Methods of Cleaning Wastewater—
A.N. Belevtsev, USSR
2:15 p.m. Wastewater Treatment for Reuse and Its Contribution
to Water Supplies—John N. English, Howard P.
Warner, Irwin J. Kugelman, EPA, Cincinnati, Ohio
3:00 p.m. Break
3:15 p.m. Cleaning Wastewater in Lacquer and Paint
Production—I.N. Myasnikov, N.Y. Norobyeva, L.V.
Gandulina, Y.V. Kedrov, USSR
4:00 p.m. Discussion
4:30 p.m. Adjourn

Wednesday, May 10

9:00 a.m. Opening Remarks—Harold P. Cahill, Jr.
9:15 a.m. Address—Francis T. Mayo
9:30 a.m. Training for Use of Advanced Wastewater Treatment
Equipment and Facilities—Fank Sebastian, Envirotech,
Menlo Park, California
10:15 a.m. Break
10:30 a.m. Construction to Facilities for Separating Sludge Mixture
in Biological Cleaning of Wastewater in the Chemical
Industry—I.V. Skirdov, S.I. Kol'Tsova, K.M.
Morozova, USSR
11:15 a.m. Contactor Design for Ozonation of Wastewater—
Edward J. Opatken, EPA, Cincinnati, Ohio
12:00 Noon Discussion
12:15 p.m. Lunch
1:30 p.m. Joint Cleaning of Mixed Industrial and Municipal
Wastewater—N.V. Pisanko, USSR
2:15 p.m. Closed Process Water Loop in NSSC Corrugating
Medium Manufacturer—John W. Collins, EPA,
Cincinnati, Ohio
3:00 p.m. Discussion
3:30 p.m. Adjourn